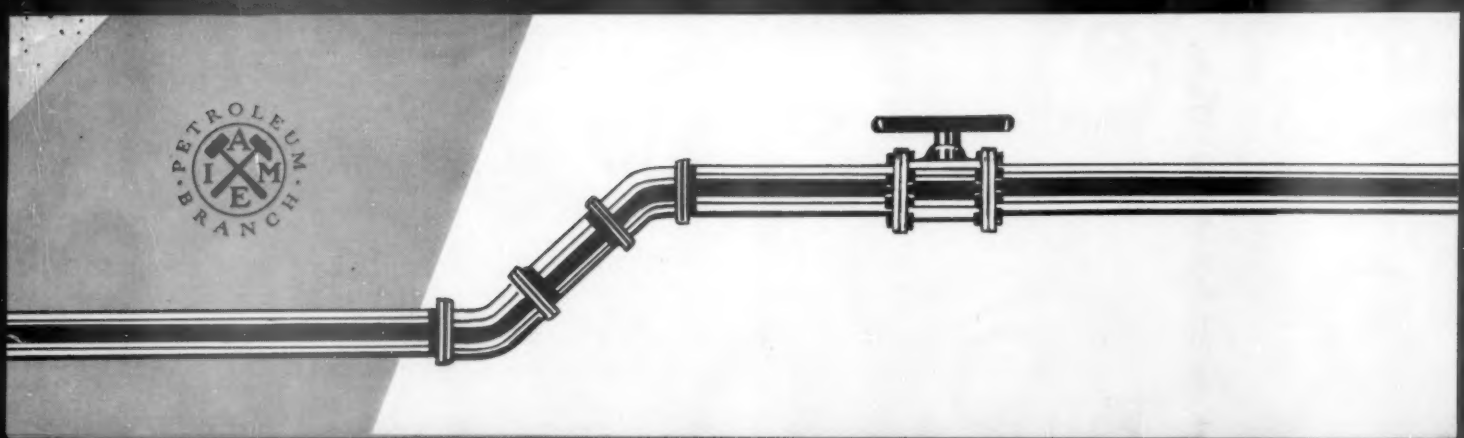
FEBRUARY 1955

ROBERT B. GILMORE 1955 PETROLEUM BRANCH CHAIRMAN

JOURNAL OF PETROLEUM TECHNOLOGY



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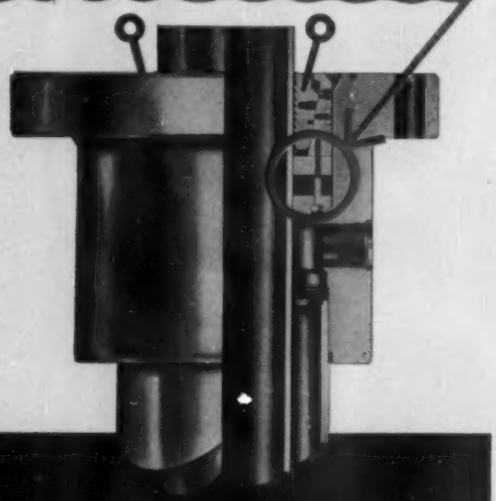

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On the Cover: Pictured are the two primary subjects of this issue, i.e., Robert B. Gilmore, new Petroleum Branch chairman for 1955, and a side perspective of a drainhole operation. A feature article on Gilmore is presented on page 9. Papers discussing the effect of drainhole drilling on production start on pages 11 and 45, and page 30 of the Transactions section.

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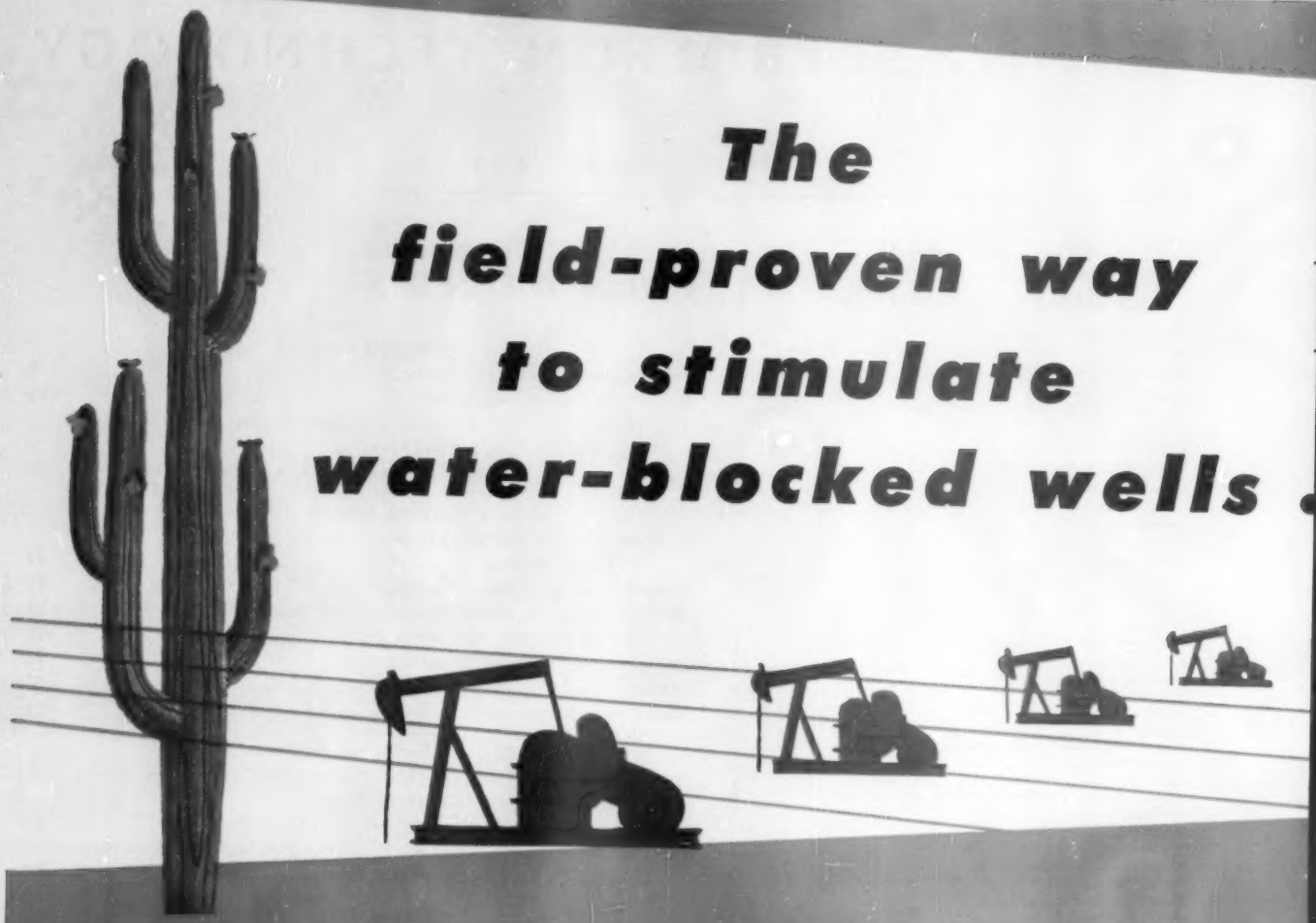

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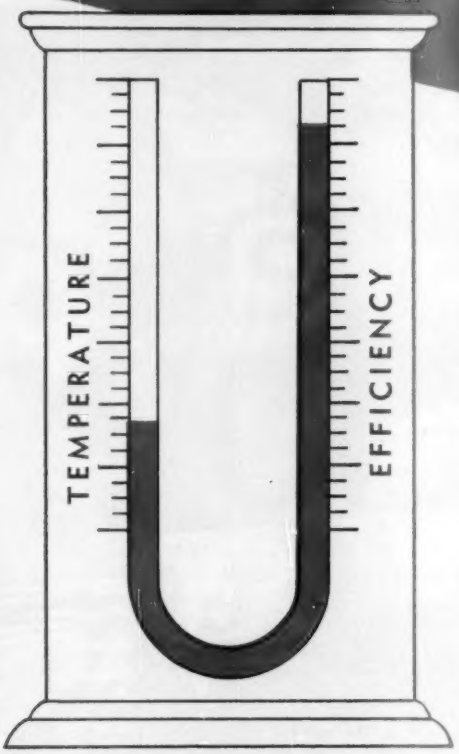

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ROBERT B. GILMORE

Chairman, Petroleum Branch, AIME

1955

IF you set out to search *Roget* and *Webster* for a few words that characterize Bob Gilmore you might look a good while, but you would be likely to settle on these three: *quiet; competent; effective*. Either on first acquaintance or after years of close relationship with him, these are the qualities you see and admire in him most. And they cover a lot of ground.

His quietness is but a manifestation of his stability, for he is the completely predictable person. Call him at any hour of the day or night about a football lottery or an evaluation job, and you find him in the same mood of good humor and ready to talk as long as you want to talk. He makes like he doesn't know much about what's going on. But ask him a question and he is likely to say, "Shoot, I donno . . .", and then go on and give you an answer with more lagniappe than a Canal Street candyman ever gave. Also, he would lead you to believe that he doesn't know many people; but go out on the street with him in Houston, Los Angeles, Tulsa, or New Orleans, and he will speak to more people by first name than you would in your own home town.

Competence and effectiveness go hand-in-hand, as applied to Bob, for they mean a breadth of capacity to join in a seemingly endless number of activities and do an impressive job in all of them. In business he is a senior vice-president of DeGolyer & MacNaughton in Dallas in charge of the Mid-Continent area. Professionally, he is always involved in two or three AIME jobs, is a member of the AAPG, the National Society of Professional Engineers, the Engineers Club of Dallas, the Dallas Petroleum Engineers' Club, the Nomads, the American Association for the Advancement of Science, and is a registered petroleum engineer in Texas and California. In civic life he is president of the Preston Hollow Dad's Club, and a member of the Dallas Chamber of Commerce. He is, last but not least, an active worker in the Preston Hollow Methodist Church of Dallas.

OUR friend grew up in the oil business. His father, who died in 1953, spent his active business life in the petroleum industry in Tulsa. This influence and location led Bob to attend the University of Tulsa, where he graduated in petroleum engineering in 1939. He served a hitch with Shell in between his starting in the University and graduation, and then returned to that company after graduation. He continued there until joining DeGolyer & MacNaughton in Aug., 1941.

A story lies in his joining DeGolyer & MacNaughton. It seems that Bob was recommended to L. W. MacNaughton, who decided to take a look and went to a rather remote community in Oklahoma to see Bob. Upon arriving at the company office there, he was directed to a certain lease, where Bob was supposed to be at work. Arriving there, he was directed to a second lease—and finally spent the afternoon driving through muddy roads to points where Bob had just been. He finally found Bob coming out of a back shed on one of the leases, and the evidence seemed to indicate that a poker game had been going on. MacNaughton hired Bob, explaining later that "the hiring was admittedly not entirely on his engineering experience and ability, because I knew little about that, but I felt that a man who could lay so many plans so well would be worth hiring."

SINCE the time MacNaughton "caught up" with Bob and he decided to move to Dallas, his rise has been quiet but constant, as he would have it. After nine years he was a vice-president and director of the firm, then continued to progress to the position of senior vice-president in charge of all Mid-Continent operations.

Bob also has another top notch petroleum "man" in the family. Gracious Mrs. Bob (Kathleen) Gilmore holds a BS degree in geology and has done graduate work in this field. She has held positions as editorial assistant of the AAPG *Bulletin*, with Superior Oil Co., and with Standard Oil Co. of Kansas. Now, in addition to caring for four charming daughters (Betsy, 12, Judy, 9, Patty, 7, and Sally, 2½), she correlates the seismograph records at Southern Methodist University.

Bob's service to AIME has been through several offices. For the past three years he has been the chairman of the Production Review Committee, which is charged with the responsibility of producing the annual *Statistics* volume. In 1950 he was Petroleum Branch treasurer, and he has held several local section offices.

HE has definite ideas about what he intends to do as chairman of the Petroleum Branch in 1955. Bob told a Delta Local Section meeting recently that his goal is to get "larger drinking glasses for use at social hours prior to local section meetings." Actually, he has three objectives which he will stress, in addition to those sought by his predecessors. They are: (1) to strive to broaden the outlook of the Branch to provide more papers and activities of interest to those petroleum engineers who have progressed to the management level; (2) to develop more interest in Student Chapters and to encourage students to become Student Associates of the AIME; and (3) to endeavor to interest more high school students in studying petroleum engineering when they start to college.

As the new Petroleum Branch chairman he will undoubtedly approach his task with the same quiet efficiency and confidence that has characterized all of his activities of the past.

R. W. TAYLOR AND JOE B. ALFORD

H. DeWITT SMITH
AIME
President
1955

H. DeWitt Smith sits behind his desk at 14 Wall St., New York, and talks easily and knowledgeably of many things. The sun streams through the window at his back and plays strange light patterns on the map of Africa on the wall to his left. The conversation ranges from Alaskan mining camps to Mexico, to South Africa, to England, Bolivia, and Chile. Through all the years of his association with mining, his chief interest has been copper. The winning of that metal has brought Smith into contact with some pretty rugged living. Today he is still active in South African copper mining. He retired as a vice-president of Newmont Mining Co. in Sept., 1954, but is still a member of the board, chairman of O'okiep Copper Co., Ltd., and consulting engineer for O'okiep and Tsumeb.

From the time he joined Newmont, Smith participated in many large copper property merger transactions, including Rhodesian Congo Border Concession, Ltd.—Bwana M'Kuba; Phelps Dodge—Calumet & Arizona; and the Phelps Dodge purchase of United Verde. It is with the development of Newmont's South African ventures that Smith is most closely identified.

As the conversation moves from one mining topic to another, he ties the minerals industry history of the last 50 years into a unified whole. As the story unfolds he pauses for a moment and then ponders that "The romance seems to have gone out of mining for a lot of people." Smith doesn't agree.

"If there is no longer romance in the minerals industry it is only because no one wants to find it there."

Born Sept. 30, 1888 in Plantsville, Conn., H. DeWitt Smith received his EM from Yale's Sheffield School in 1910. His travels started early in his career. As one of the last junior engineers trained by Joshua Edward Spurr, he saw most of the western part of the U. S. and much of Mexico.

In 1924 Smith put aside the rough clothes of a mining man and went into the industrial department of the New York Trust Co. "One of the remarkable things about the department at that time, was that the personnel consisted largely of mining engineers." Mr. Smith performed such diverse duties as operating a silk ribbon business and a milking machine company before he left the bank to return to mining and United Verde. Finally, in 1930 he joined Newmont. Since then, there has been only one break in the relationship. Smith was executive vice-president of the Metals Reserve Co., Reconstruction Finance Corp. subsidiary. He was in charge of all domestic, Canadian, and Mexican metals procurement activities, from 1941 to 1944.

While with Metals Reserve he established a reputation for quickly cutting away red tape and superfluous negotiations on contracts. One representative of a large company walked into the Metals Reserve offices expecting hours of wrangling over vague details. Fifteen minutes later he and his lawyer were walking out the door, the executive recalls, with a signed contract. The soundness of the contracts arranged by Metals Reserve was proven after the end of the war when not one of its agreements had to be renegotiated. An escape clause in each pact elaborated on the exact procedure to be followed for its termination or at the end of hostilities.

Smith joined the Institute in 1911 and has been active in its affairs for many years, holding office as chairman of the Nominating Committee in 1939, as a director, chairman of the Seeley W. Mudd Memorial Fund Committee, and chairman of the 75th Anniversary Committee. One of his prime objectives as 1955 president of the AIME will be to strengthen the grass roots movement among the sections that was started during previous presidencies.

He is vitally concerned with the problem of attracting young men to the mining industry, and has been instrumental in the Newmont program which brings five young men to the U. S. from South Africa each year. The South Africans study in U. S. schools for three years under the plan. Many of his training ideas evolved from the United Verde mining training program that operated in the years following World War I.

Smith married Ellen Dawson Burke of Plainfield, N. J., in 1916. They have three children, C. DeWitt Smith, Mrs. Alfred Sanford, II, and Mrs. J. Clifton Rodes. C. DeWitt Smith is with St. Joseph Lead Co., carrying on the family tradition of making one's own way.

If there is one thing in the world that will distract Smith from mining and the romance of copper, it's surfcasting. Nantucket beaches, early in the morning or just before sundown are his favorite spots. His biggest catches have been a 9½ lb bluefish and a 23½ lb striped bass, both hooked and landed off Nantucket.

★★★

FEATURE ARTICLE

THE EFFECT of SLANT HOLE, DRAINHOLE, and LATERAL HOLE DRILLING on WELL PRODUCTIVITY

ALVIN E. ROEMERSHAUSER
MURRAY F. HAWKINS, JR.
MEMBER AIME

LOUISIANA STATE UNIVERSITY
BATON ROUGE, LA.

Introduction

Methods have been developed for drilling (a) slant holes[1] and (b) one or more curved holes from a common central hole[2,3] in producing formations. These wells will have productivities exceeding that of a single hole drilled normal to and fully penetrating the producing stratum, other factors being equal. This increase is due to the decrease in resistance to flow in the vicinity of the wellbore by an increase in the cross section exposed to flow with increasing footage drilled in the formation and due to the geometrical arrangement of the holes with respect to the drainage radius or boundary. Where other factors are not equal, for example, where zonal damage exists in the single, fully penetrating hole but not in the slant or curved holes, additional increases in productivity will accrue.

Many of these wells have been drilled in the past and are currently being drilled with various results reported. While the authors are aware of some of the practical aspects of drilling and completing these multiple, curved holes, it is their hope to provide some basic data on the improvement in productivity to be anticipated in these wells for a number of hole arrangements or patterns.

Model Studies

Electric analogue or model studies have been used for solving some reservoir fluid flow problems in which the mathematical solutions are unknown, too approximate or too complex. For example, recent studies have used this method to determine the effect of shot density, diameter, and depth of penetration of gun perforations on well productivity[4,5]. The success of these studies depends upon the analogy between Ohm's Law for electrical flow and Darcy's Law for incompressible fluid flow in homogeneous rock. Where a geometrical scale reduction is desired, a single scale factor is applied to all dimensions.

Following along lines similar to the gun perforation tests, the present experiments have been performed to evaluate the benefit in well productivity of slant and curved holes as applied to incompressible fluid flow in homogeneous rock from a radial boundary. In order to make the results of greatest use, the studies have been reported on the basis of 40 acre well spacing (660 ft radial boundary) and the well patterns used have conformed to those presently obtainable with proven drilling tools. Accordingly, the discussion will be limited to the following classifications or patterns, illustrated in Fig. 1 and defined as follows:

(1) Slant Hole — Fig. 1a — a single hole drilled at an angle other than normal to the producing stratum, and fully penetrating that stratum. This may occur in wells drilled directionally through near horizontal strata or vertical holes drilled through dipping strata.

(2) Drain Holes — Fig. 1b — one or more holes drilled from a central borehole with a radius of curvature of 8 to 12 ft and subsequent horizontal penetration up to 50 ft.

(3) Lateral Holes — Fig. 1c — one or more holes drilled from a central borehole with a radius of curvature of about 30 ft and a total footage of about 50 ft from the central borehole.

In addition reference will be made to partially penetrating wells (Fig. 1d) which are drilled normal to the producing stratum but do not fully penetrate it.

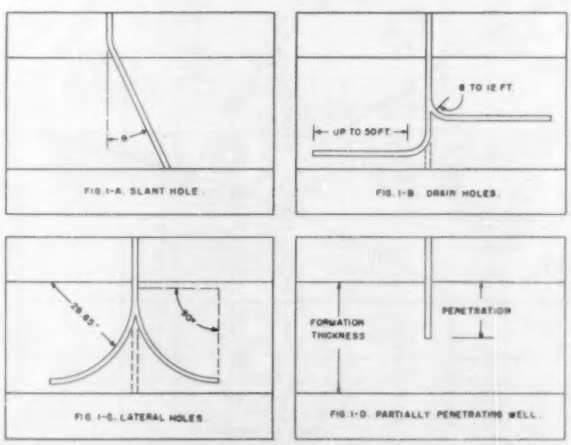

Fig. 1 — Completed drain holes in limestone formation.

[0]Graduate Fellow and Professor of Petroleum Engineering at Louisiana State University.

Manuscript received in Petroleum Branch office on June 18, 1954.

[1]References given at end of paper.

Fig. 2 — Photograph of model tank.

Fig. 3 — Photograph of electrodes representing various patterns.

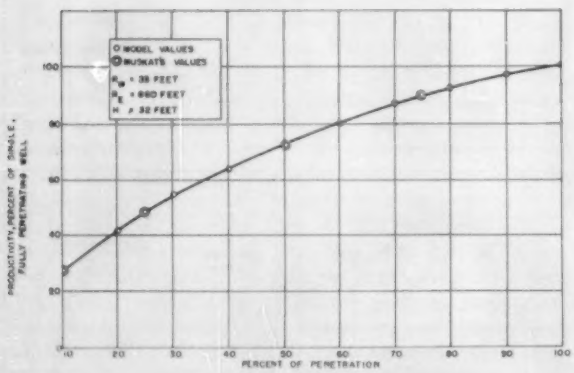

Fig. 4 — The effect of penetration on productivity.

The electrical model consists of a cylindrical plastic tank about 6 ft in diameter filled with an electrolyte to depths up to 12 in as shown in Fig. 2. A vertical, fully penetrating well, with which all other well patterns are compared, is represented by a straight piece of No. 4 solid, bare, copper wire suspended vertically at the center and extending to the bottom of the tank. The drainage radius is represented by a cylindrical copper sheet, 6 ft in diameter and 12 in. in height, resting on the bottom of the tank. On the scale selected the model represents a borehole of 0.350 ft radius (about 8½ in diameter), a drainage radius of 115 ft and formation thicknesses up to 32 ft depending on the level of the electrolyte in the tank. Well models representing various drainhole and lateral hole patterns, as previously defined, are also constructed of No. 4 copper wire bent to curvatures on the proper scale. Some of the electrode models are shown in Fig. 3 in which it can be observed that, where more than one drain hole is drilled, the holes are arranged symmetrically about the central hole and on one or more vertical levels, so as to give approximately optimum productivity. Lateral holes were arranged on one level only, symmetrically about the central hole. All curved hole arrangements were suspended at the center in the electrolyte to represent a 90 per cent vertical penetration of the formation.

A Type 650-A General Radio Impedence Bridge was used to measure the electrical resistance between the center electrode or other electrode pattern and the outer cylinder. As the model represents the 40 acre unit only to a radius of 115 ft, an additional resistance R_e, was added to all readings, assuming radial flow from 115 ft to the 660 ft radius. This additional resistance was calculated from the measured specific resistance of the electrolyte. The resistance, R_o, between the single, vertical, fully penetrating electrode and the outer cylinder, corrected to 660 ft equivalent radius by the addition of R_e as defined previously, was taken as the reference with which all other well pattern systems were compared. If the resistance between any other electrode pattern and the outer cylinder be R_x, as well productivity varies inversely with the resistance, the percentage increase in well productivity of any electrode pattern over the single, vertical, fully penetrating well is given by

$$\text{Percentage increase} = 100\left(\frac{R_o + R_e}{R_x + R_e} - 1\right)$$

In order to check the validity and the accuracy of the model, it was used to solve the problem of the partially penetrating well. As this particular problem has been solved mathematically by Muskat,[6] the comparison of the data obtained by both methods, shown in Fig. 4, indicates an adequate model.

Results

(1) Slant Holes — The effect of drilling a completely penetrating hole at an angle other than normal to the strata is shown in Fig. 5. Moderate improvement is noted with increasing angle of penetration. The slightly greater increases in the thicker formations at the same angle are due to the closer approach of the boreholes to the drainage radius in the thicker formation. As only relative angles are important, the same improvement is to be anticipated in a vertical hole drilled through a formation dipping at the indicated angle over a well penetrating normally, provided that the reference is 40 reservoir acres and not 40 surface acres.

(2) Drain Holes — Fig. 6 and Fig. 7 assume 90 per cent penetration, i.e. the lowest portion of any of the holes is 3.2 ft and 1.6 ft respectively above the base of the 32 ft and 16 ft thick formations. As mentioned previously, the drain holes were oriented spatially to give approximately best productivities. Fig. 6 indicates the greater benefit per drain hole in the thinner formation, but as would be expected, four drain holes in the 32 ft formation gives about the same improvement as two drain holes in the 16 ft formation. A diminishing rate of improvement per additional drain hole is noted in all measurements, and the ultimate improvement will approach asymptotically the percentage improvement calculated for a well reamed out to a radius equal to the maximum horizontal penetration. The effect of greater horizontal penetration is shown in Fig. 7 where values up to 50 ft horizontal penetration are plotted.

(3) Lateral Holes — Fig. 8 shows a trend for lateral holes quite similar to that for drain holes except that there is no horizontal penetration after the hole has been turned 90°, i.e. to the horizontal. All results apply to lateral holes which have been turned the full 90°.

Fig. 9 is interesting in that it shows a general increase in productivity for all methods as a function of the total footage drilled in the producing formation. It should be mentioned at this point that the productivities for all curved hole patterns would have been slightly increased had a fully penetrating central borehole been drilled in addition to the curved holes. It is observed that slant hole drilling gives the best increase per foot drilled, while, as might be expected, the greatest total benefit is obtained from the drain holes with 50 ft of horizontal penetration. The lower curve is an average for drain holes with 14.1 and 20 ft of horizontal penetration. It approaches a limit of about 200 per cent increase, which is the calculated increase expected if the hole were reamed out to about 17 ft. The upper curve is an average for drain holes with 35 ft and 50 ft horizontal penetrations, lateral holes turned through 90° on a 28.65 ft radius, and slant holes. This curve approaches a limiting value of about 300 per cent. The numbers beside the various points indicate the number of drain holes or lateral holes drilled to achieve the plotted value of total footage and, in the case of slant holes, the angle of penetration.

Application

While no reference has been made to well completion, it is presumed that the results may be applied equally to cased and open holes, provided that the same completion efficiency exists in the patterns under comparison. The results presented from these studies are based upon the assumption of steady-state flow of homogeneous, incompressible fluids in isotropic formations of uniform permeability and thickness. Because of these assumptions, it is believed that for most field applications the actual improvements to be expected are greater than those reported. For example, as shown in Fig. 10, where the well spacing is less than 40 acres (660 ft drainage radius) greater improvement will result. Where the new hole or holes drilled extend beyond a region of low permeability, as from zonal damage during drilling and completing the original straight hole, or where the new hole or holes extend to regions of increased permeability, as for example in fracture type formations, increased benefits over those predicted here are to be expected, the magnitude depending upon the particular areal extent and ratios of the permeabilities involved.

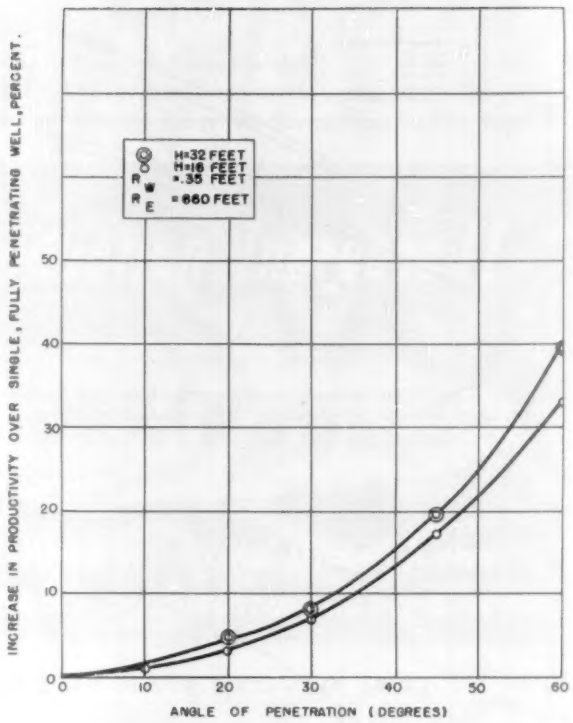

Fig. 5 — The effect of angular penetration and formation thickness on productivity.

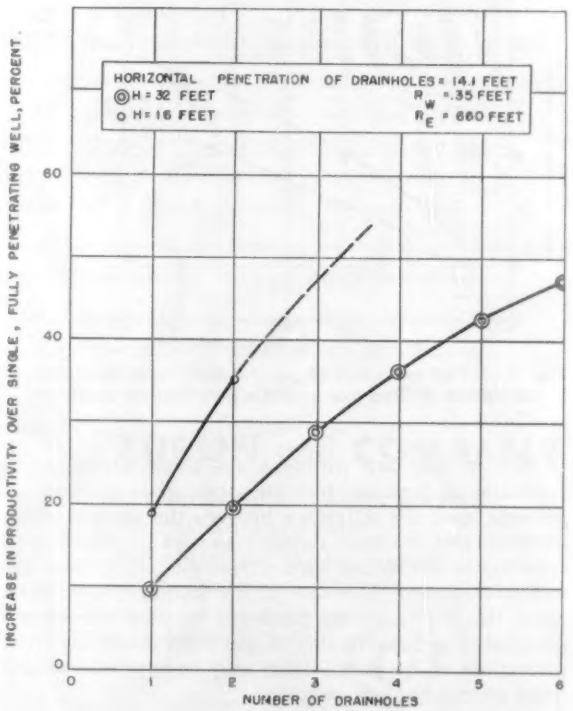

Fig. 6 — The effect of drainhole density and formation thickness on productivity.

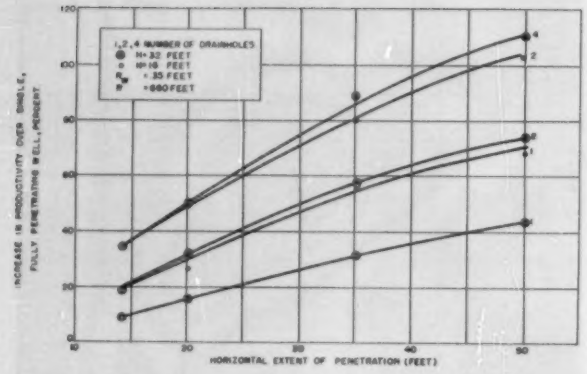

Fig. 7—The effect of horizontal penetration and formation thickness on producivity for drainhole drilling.

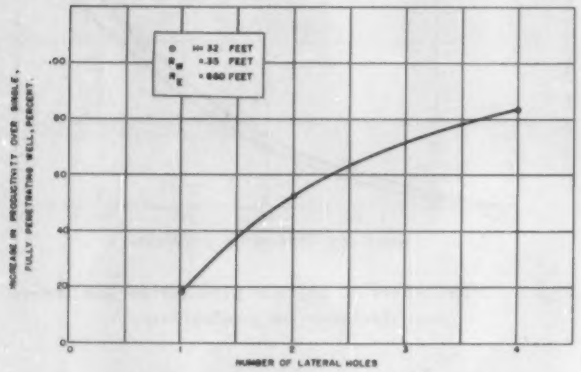

Fig. 8 — The effect of lateral hole density on productivity.

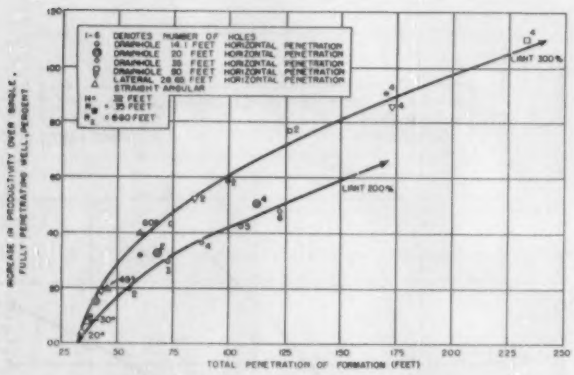

Fig. 9 — The variation of productivity with total feet of formation drilled for various penetration methods.

As both gas flow formulae and those pertaining to gravitational drainage[7] indicate a rate of production dependent upon the difference between the squares of the wellbore and drainage radius pressures or fluid heads, resulting in a concentration of pressure drop near the wellbores greater than that of the incompressible fluid, again the improvements predicted by these studies are minimal. The deliverability of gas wells producing from formations of low permeability may be improved several times over the values indicated.

Finally, further improvement over the indicated values may be anticipated in oil producing formations where large draw down pressures cause reduced oil

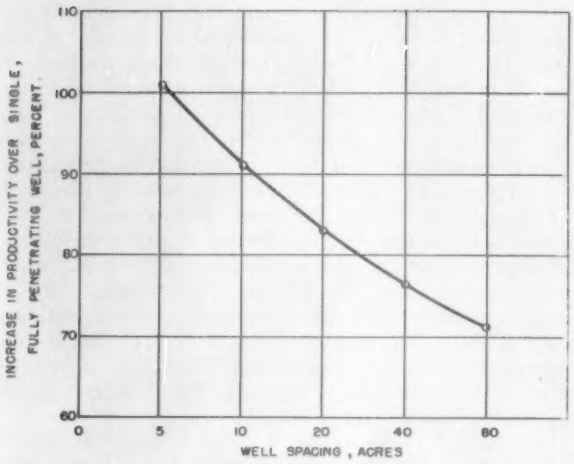

Fig. 10 — The effect of well spacing on productivity increase for two drain holes, 50 ft horizontal penetration, H = 32 ft, R_w = 35 ft.

permeability due to the release of gas from solution in the vicinity of the wellbore. Similar remarks apply to gas condensate wells in which retrograde liquid is deposited as a result of large pressure drops in the vicinity of the wellbore.

Conversely, there are some instances where the anticipated improvement will be less than predicted here; for example, when the well is drilled fortuitously into a permeable portion of a reservoir which is surrounded by less permeable rock.

Acknowledgments

Appreciation is expressed to the Delta Section (New Orleans) of AIME for the gift of the General Radio Impedence Bridge used in these studies and to the Humble Oil and Refining Co. for establishing a graduate fellowship in petroleum engineering at Louisiana State University under which much of this work was accomplished; although neither has been otherwise in any way connected with these studies.

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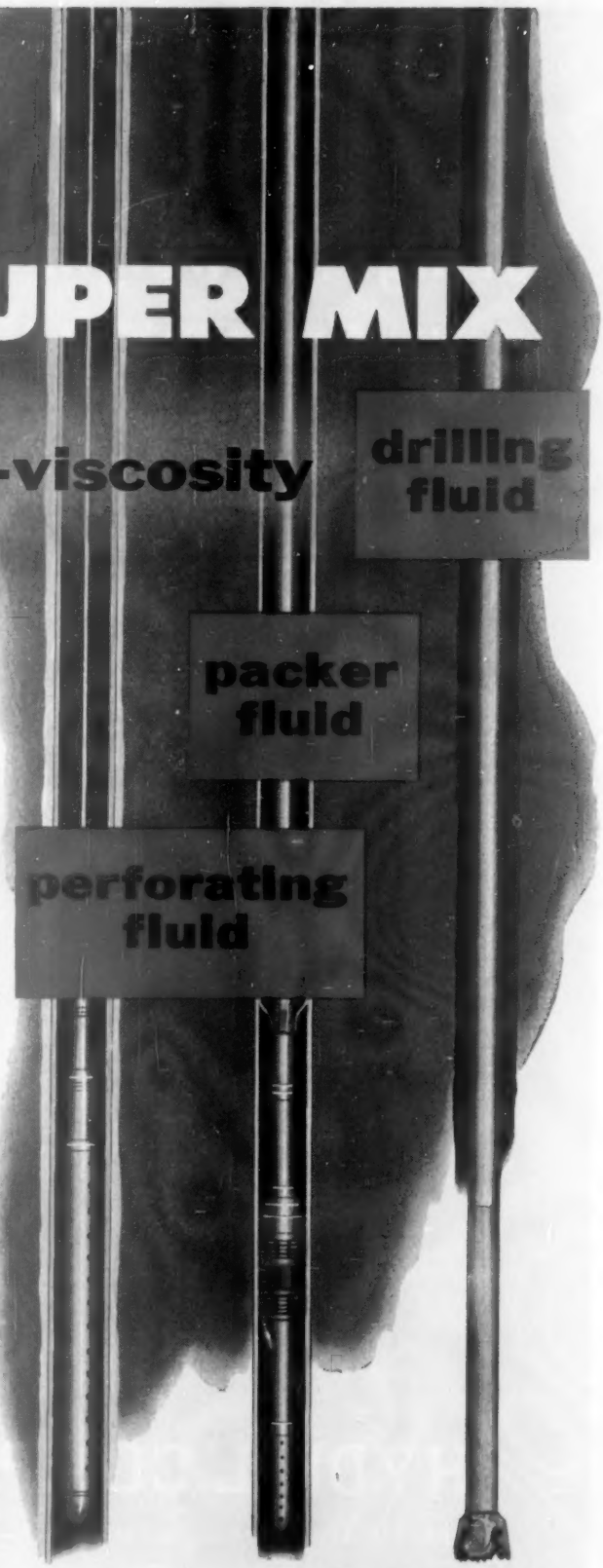

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*Effectiveness of Gun Perforating, Journ. Pet. Technology, January, 1954.

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5 —15# J-55	8,850	10,720	287
5 —15# N-80	11,590	12,250	328
5 —18# N-80	15,200	13,040	421
5½—14# J-55	5,640	9,900	244
5½—15.5# J-55	6,860	10,420	288
5½—17# J-55	8,000	10,870	330
5½—17# N-80	10,470	12,380	376
5½—20# N-80	13,480	13,100	467
6⅝—20# J-55	5,440	10,260	360
6⅝—24# J-55	7,560	11,100	471
6⅝—24# N-80	9,870	12,670	538
6⅝—28# N-80	12,640	13,320	663
7 —20# J-55	4,440	10,000	352
7 —23# J-55	5,850	10,700	436
7 —23# N-80	7,640	12,200	497
7 —26# J-55	7,220	11,210	518
7 —26# N-80	9,460	12,800	591
7 —29# N-80	11,320	13,250	685
7⅝—26.4# J-55	5,350	10,850	499
7⅝—26.4# N-80	6,990	12,370	569
7⅝—29.7# N-80	8,730	12,950	677
7⅝—33.7# N-80	10,790	13,100	779
8⅝—32# J-55	4,870	10,090	585
8⅝—36# J-55	6,080	10,650	674
8⅝—36# N-80	7,950	12,160	769
8⅝—40# N-80	9,580	12,680	897
9⅝—36# J-55	3,950	10,100	634
9⅝—40# J-55	4,920	10,610	744
9⅝—40# N-80	6,280	12,130	850
9⅝—43.5# N-80	7,610	12,570	966
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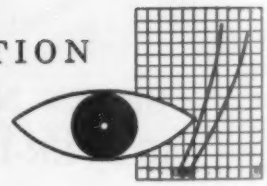


JOE B. ALFORD

EXECUTIVE SECRETARY
PETROLEUM BRANCH, AIME

Petroleum Branch Financial Condition

The Petroleum Branch had an excellent financial year in 1954. Total Branch income was $198,075, and expenses $192,144, leaving a surplus of $5,930. The year's income was $33,296 more than 1953; about half of the increase coming from advertising revenue and the remainder from membership dues and publication sales. Table 1 shows the breakdown of income and expense, and the percentage of each major division of the total, for 1954.

Since the organization of the Branch in 1949, the Branch Executive Committee has had the policy of operating in the black, and this has been done since 1950. We have also operated on the basis of plowing as much money as possible back into future development, and during these years have invested about $18,000 in sales promotion on advertising and membership development, that would have otherwise been surplus. This investment is already paying off well through a growing membership and advertising volume. Both result in increasing income.

Table 1 — Petroleum Branch Income and Expense for 1954

INCOME	Amount	Per cent of Total
Membership dues and initiation fees	$111,188	56.1
Advertising and publications sales	86,014	43.5
Miscellaneous	873	.4
Total Income	$198,075	100
EXPENSE		
Membership and Sections: (Local Section refunds; Petroleum Branch office; membership promotion; Engineering Societies library)	$ 51,629	26.9
Publications: (*Petroleum Technology; Transactions; Statistics;* miscellaneous)	101,346	52.7
Administrative: (Branch share New York office, pensions; insurance; AIME directory supplement)	39,169	20.4
Total Expenses	$192,144	100
Surplus income over expenses	$ 5,930	

Table 2 — Comparison of AIME Income by Branches, 1950-1955

(1955 Figures from Tentative Budget for Year)

	Mining	Metals	Petroleum
1955	$314,544	$180,847	$230,009
1954	303,269	175,078	198,075
1953	309,315	181,690	164,779
1952	290,191	163,179	140,009
1951	256,722	138,346	127,007
1950	240,623	130,514	122,648
Total income increase for 6-year period	$ 73,921	$ 50,333	$107,361

Table 2 shows a comparison of income of the three Branches of AIME by years from 1950 through 1955, and Table 3 shows the amount of increase or decrease by Branches in the same period. These figures reveal that the Petroleum Branch got a slow start, but has had a steady growth since, and by the end of this year will have increased its income by about $107,000 in the six-year period.

Table 3 — Increase or Decrease of AIME Income by Branches, 1950-1955

	Mining	Metals	Petroleum
1955 over 1954	$11,275	$ 5,769	$31,934
1954 over 1953	(6,046)	(6,612)	33,296
1953 over 1952	19,124	18,511	24,770
1952 over 1951	33,469	24,833	13,002
1951 over 1950	16,099	7,832	4,359

The primary basis for this financial good health is growth in membership—along with increasing recognition of the petroleum engineer in the oil industry. Table 4 shows a comparison of AIME membership by grades in each Branch at the beginning of 1950 and 1955. These figures show that the Petroleum Branch had an over-all membership increase of 51.5 per cent during the five-year period.

In spite of this excellent growth pattern—the credit for which is due to many members—we believe the Petroleum Branch is just getting started good. A projection of the same growth rate will give the Branch a membership of 11,000 by 1960 and 15,000 by 1965. If this occurs, we can have an income of $350,000 and $500,000 in the same years.

Sound optimistic? Admittedly it does, but the potential is there, and it can be done. When it is done we will have lower dues, better publications, more service to members, and render a far better service to the industry. The goal is worth the effort.

Table 4 — Analysis of AIME Membership by Branches by Grades, 1950 and 1955

MINING BRANCH	Jan. 1, 1950	Jan. 1, 1955
Members and Associates	6,519	8,059
Junior Members	2,047	1,721
Students	2,599	940
	11,165	10,720
METALS BRANCH		
Members and Associates	3,054	4,240
Junior Members	959	1,071
Students	1,218	574
	5,231	5,885
PETROLEUM BRANCH		
Members and Associates	2,844	4,014
Junior Members	893	2,711
Students	1,134	665
	4,871	7,390

★★★

SEVEN NEW LOCAL SECTIONS FORMED during 1954 AS EVER-INCREASING BRANCH GROWTH CONTINUES

In 1954 the Petroleum Branch continued the policy established by the Executive Committee in 1952 to "take the Branch to its membership through the establishment of new local sections." Seven new local sections were organized during the year just passed, and the last remaining Branch "chapters" voted to convert to local section status. This brings the total of AIME local sections predominantly petroleum in membership to 26.

Only nine petroleum local sections were in existence when the Executive Committee made its decision in 1952 to actively encourage formation of new sections. Many of these sections encompassed areas which included hundreds of miles, making it impossible for members to attend meetings of their local section often held in distant cities. It has been the plan of the Petroleum Branch officers and staff to break down these larger territories into two or more sections, and this has made local section meetings more accessible to hundreds of members.

Also, the plan encompassed an active program of establishing new local sections in areas where a sufficient number of members and prospective members are located. Three of the local sections organized in 1954 were of this type.

Still another goal of the 1952 plan was to have the AIME by-laws amended to allow "overlaying" local sections. This proposal was adopted, and now it is permissible to organize a petroleum local section in areas where a local section exists serving members of more than one Branch of the AIME. Five of the sections organized in 1954 overlay sections serving other Branches.

The establishment of the new local sections to better serve the Petroleum Branch membership has been an important consideration in the ever-increasing growth of the Branch. This growth is illustrated by the following figures, which do not include changes of status and student associates.

1951—344 new members
1952—510 new members
1953—691 new members
1954—930 new members

Organization meetings for two new sections were held in early April, 1954. Executive Secretary Joe B. Alford met with a group in Pampa, Tex., on April 8 to help organize the Panhandle Local Section. On April 9, he went to Guymon, Okla., to aid in the organization of the Hugoton Local Section. The Panhandle Section has increased its membership by 152 per cent since its organization with 25 members. The Hugoton Section was formed when the Tri-State Oil and Gas Association voted to become an AIME Local Section, and 40 per cent gain has been shown in their membership since organization.

The Hobbs Petroleum Section was established at a meeting in Hobbs, N. Mex., on April 20. One hundred members and potential members were present when it was voted to petition the AIME Board of Directors to allow formation of a section to overlay the Carlsbad Potash Section. Twenty new members have been added to the original 55 in this Section.

On Aug. 26 in a meeting at Barcelona, Venezuela, a movement was put into motion that eventually resulted in the organization of the Venezuela Local Section. The organizational meeting attracted 79 persons, and the Board of Directors voted to allow this section to be formed to include all of the Republic of Venezuela.

AIME members interested in the Petroleum Branch started early in the summer with plans to organize the New York Petroleum Section to overlay the New York Local Section. The Board of Directors approved their petition on Dec. 15.

PANHANDLE LOCAL SECTION: Includes Texas counties of Hartley, Moore, Hutchinson, Roberts, Hemphill, Oldham, Potter, Gray, Wheeler, Deaf Smith, Randall, Armstrong, Donley, Collingsworth, Parmer, Castro, Swisher, Hall, Briscoe, and Childress.

HUGOTON LOCAL SECTION: Includes Texas counties of Moore, Hansford, Hartley, Dallam, Sherman, and Ochiltree; Oklahoma counties of Cimarron, Texas, Beaver, and Harper; Colorado counties of Prowers and Baca; and Kansas counties of Morton, Stevens, Seward, Meade, Clark, Ford, Gray, Haskell, Grant, Stanton, Hamilton, Kearny, Finney, Scott, Wichita, and Greeley.

HOBBS PETROLEUM SECTION: Includes New Mexico counties of Lea, Eddy, Chaves, and Roosevelt; Texas counties of Gaines and Yoakum.

VENEZUELA LOCAL SECTION: Includes all of the Republic of Venezuela.

NEW YORK PETROLEUM SECTION: Includes New York counties of Bronx, Queens, Kings, Richmond, Rockland, Nasseau, Orange, Putnam, Suffolk, Westchester, and Manhattan; New Jersey counties of Bergen, Essex, Hudson, Middlesex, Monmouth, Passaic, Morris, Somerset, Sussex, and Union.

SAN JOAQUIN VALLEY SECTION: Includes California counties of Fresno, Kings, Tulare, Kern, San Luis Obispo, and a portion of Santa Barbara.

ILLINOIS BASIN PETROLEUM SECTION: Includes same area as does the St. Louis Local Section.

SOUTHERN CALIFORNIA PETROLEUM SECTION: Includes the same area as does the Southern California Local Section.

Another section officially established early in 1954 was the San Joaquin Valley Section. This group overlays portions of the Southern California Local Section and San Francisco Section and was a subsidiary group of the Pacific Petroleum Chapter prior to organizing into a local section. Most of the work of organizing this local section took place in 1953, but because of some questions as to section boundaries it was not approved by the Board until early 1954.

The only two remaining chapters within the Petroleum Branch structure at the beginning of 1954 were the Illinois Basin Chapter and the Pacific Petroleum Chapter. A newly-named Illinois Basin Petroleum Section was approved by the Board on Dec. 15, and the Pacific group has voted to change to local section status, although the Board has had no opportunity to take action on their petition.

During 1955 there will undoubtedly be other groups who will organize into local sections and petition for recognition. A minimum of 25 AIME members is required for this action, and there are areas at this time with sufficient members and prospective members to justify the establishment of their own local sections. Since some of the most rewarding experiences of Petroleum Branch AIME membership are received through local section functions, organization of new local sections can only mean a stronger Branch composed of members with a better understanding of professionalism in the field of petroleum engineering.

PLANNING STARTED for 1955 FALL MEETING in NEW ORLEANS

The 1953 Petroleum Branch Fall Meeting in Dallas attracted the largest attendance in the history of the Branch. The 1954 Fall Meeting in San Antonio quickly broke that attendance record by registering 2,302 persons. Now plans are being made for the 1955 Fall Meeting to be held Oct. 2-5 in New Orleans, and it is anticipated that again the attendance record will be surpassed.

Thus the Petroleum Branch Fall Meeting has become one of the major annual gatherings in the oil industry. With the offering of some 50 selected technical papers in prospect for the 1955 meeting, it assumes more of the stature of a short course in several fields of engineering. Again this year it will offer the first presentation of outstanding petroleum engineering papers produced by the industry, as well as excellent entertainment for both members and their wives.

Officers of the hosting Delta Local Section, working with the officers and staff of the Petroleum Branch, are planning all activities for the 1955 meeting on a large scale in order to accommodate the number of registrants expected. The Roosevelt Hotel, which has spacious meeting and dining rooms, is the headquarters hotel for the 1955 meeting.

In major New Orleans hotels 1,400 sleeping rooms have been reserved. This number of rooms, which is all that could be secured, probably will not be sufficient to handle the large number planning to attend; therefore, Delta Section committees are now canvassing top motels in the city to find available space for the expected crowd. Hotel rooms will be given to those who make reservations earliest; others will be placed in the most convenient motels in the city and in some cases will be required to place a deposit on their rooms in advance.

Room Reservation Forms

Forms to be used in reserving rooms for the meeting will be mailed to all members in the near future. It has been requested by the chairman of the Fall Meeting Housing Committee that no orders be placed for reservations prior to the sending of these forms. Also, it has been asked that no requests for reservations be sent directly to hotels, for they have been instructed to pass all such orders to the local Housing Committee. After the forms are returned to the Housing Committee, the hotel in which the person is placed will acknowledge the accommodations. On requests by a company for a group of rooms, 25 per cent will be placed in the headquarters hotel as long as space is available and the remainder placed in other hotels in the city.

All plans have been made in keeping with the principle of having plenty of space available for all events. The Roosevelt has two spacious meeting rooms located on the mezzanine floor, the Grand Ballroom and the International Room. Both will accommodate over 1,000 persons and will be used for technical sessions. It is possible that a theater close to the Roosevelt will be rented for use as a third meeting room.

These large rooms in the Roosevelt also will be used for the two annual stag luncheons, the Welcoming Luncheon and the Membership Luncheon, which will be held on Monday, Oct. 3, and Tuesday, Oct. 4, respectively. For the annual banquet and dance on Tuesday evening, both of these rooms, which are separated only by a corridor, will be used.

Ladies' Activities

Final arrangements are not complete for all of the ladies' activities or for the Monday evening social function which will be for both men and ladies. It is probable that the Ladies' Welcoming Coffee will be held in the Roosevelt's famed Blue Room. In one of the many interesting places in colorful New Orleans, a luncheon and style show will be given for the ladies on Tuesday.

Five interconnected rooms on the mezzanine floor of the Roosevelt will be used as an exhibit area. These rooms are ideally located in the vicinity of the Grand Ballroom and the International Room, and will accommodate approximately 30 well displayed booths. Registration will be held in the University Room on the third floor of the hotel on Sunday and Monday and will be moved to the mezzanine floor on Tuesday and Wednesday.

The 1955 Branch Technology Committee is now being organized and will soon start gathering papers for the technical programs. L. P. Whorton, of Atlantic Refining Co., is the chairman of this committee. After completing the appointment of his vice-chairmen to assemble papers in the various fields of technology, he will be in charge of ensuring a balanced program for the meeting.

Papers will be presented in the technical fields of drilling, geological engineering, natural gas engineering, petroleum economics, reservoir engineering, and the production engineering fields of production equipment, production operations, and well completions. The number of papers in each of these fields to be included on the program will be based on membership interest in the various fields.

Local Section Committees

Vice-chairmen and the fields in which they will work appointed at this time are: Drilling, Roy A. Bobo, Phillips; Production Engineering, R. K. Guthrie, Seeligson Engineering Committee; Reservoir Engineering, A. F. van Everdingen, Shell, R. A. Morse, Gulf, and R. G. Parker, Continental. Others will be appointed to serve as vice-chairmen in the aforementioned fields to be covered by papers at the meeting.

B. L. Francis, The Texas Co., 1955 chairman of the Delta Local Section has appointed committee chairmen

(Continued on Page 30)

TOPICS for PETROLEUM RESEARCH

A revised list of topics for petroleum research has been developed under the direction of Jack Tarner, Phillips Petroleum Co., Bartlesville, chairman of the Petroleum Branch Education Committee. It is published below for its value to the industry.

I. Reservoir Rock . . .

a. . . . porosity, permeability and capillary pressure correlated with mineral content, grain size and pore size distribution.
b. . . . properties related with the properties of common minerals that form the interstitial material.
c. . . . property variations and their effect on production behavior.
d. . . . properties as influenced by deposition.
e. . . . heat conductivity coefficients of reservoir rocks having varying degrees of liquid saturations.

II. Oil Field Water . . .

a. . . . analysis with particular reference to elements and compounds not usually determined.
b. . . . constituents and their solubility at subsurface conditions.
c. . . . simplified method for determining the presence and action of sulphate reducing and other type bacteria.
d. . . . treatment for waterflood operations.
e. . . . filtering for removal of solids and bacteria.
f. . . . radioactivity.

III. Fluid Properties . . .

a. . . . wettability and its relationship to fluid flow behavior.
b. . . . wettability as it is affected by impurities and surface active agents in oils and brines.
c. . . . surface and interfacial tension between oil, water, gas and solids as measured under subsurface conditions.
d. . . . (thermal) of complex hydrocarbon systems.
e. . . . heat transfer coefficients between fluids and reservoir rocks under multiphase flow conditions.
f. . . . viscosity of reservoir fluids at subsurface conditions predicted from analytical data.
g. . . . condensate vaporization characteristics as affected by the variation in the composition of the heptanes plus fraction.
h. . . . condensate composition as it is affected by retrograde conditions caused by pressure differentials around the wellbore.

IV. Fluid Distribution . . .

a. . . . in a reservoir rock as affected by varying fluid properties.
b. . . . as determined by laboratory restored state tests compared with actual conditions in a subsurface reservoir.
c. . . . investigation of the possibility of oil, gas, and water existing in equilibrium in the separate phases in the pores of extremely tight reservoir rocks.
d. . . . as affected by diffusion of natural gas in reservoir rocks.
e. . . . as affected by supersaturation in tight reservoir rocks.
f. . . . as affected by gas film adsorption in reservoir rocks.

V. Phase Relationship . . .

a. . . . of hydrocarbons in extreme pressure ranges.
b. . . . standardization of sampling methods and analysis technique.
c. . . . equilibrium methods for use in calculating recovery of liquids through cycling at different pressures.
d. . . . of fluids entering wellbores.

VI. Displacement . . .

a. . . . of oil from a porous medium by the action of gas.
b. . . . of oil from a porous medium by the action of water.
c. . . . of oil from a porous medium by the action of miscible fluids.
d. . . . tests as affected by film formation at the oil-water interface.
e. . . . of oil by gravity drainage.

VII. Relative Permeability . . .

a. . . . to oil, water, and gases as correlated with the properties of the reservoir rock.
b. . . . investigation, with a view to replacing Darcy's Law with a formula containing more fundamental variables.
c. . . . hysteresis effect.
d. . . . as mathematically related to capillary pressure.
e. . . . data applied to field operations.
f. . . . relationships in vugular and fractured rocks.

VIII. Field Production . . .

a. . . . history as related to fluid properties.
b. . . . practices for achieving maximum oil recovery from thin oil columns.
c. . . . rates as they bear upon ultimate oil recovery, especially when the rates drop the pressure below the bubble point.

IX. Secondary Recovery . . .

a. . . . by water injection as predicted from tests on restored state or native state cores.
b. . . . by water injection as it is affected by the free gas saturation of the reservoir rock.
c. . . . by use of heat and/or combustion underground.
d. . . . by use of diluents, solvents, and chemicals.

e. . . . operations and the use of plugging agents.
f. . . . role of oil-water emulsions.
g. . . . tracer compounds to determine fluid bypassing.
h. . . . flood-water treatment.
i. . . . use of engine exhaust gases.
j. . . . role of detergents in water flooding.

X. Laboratory . . .

a. . . . procedures for separation of gas and oil from composite mixtures that are more representative of field operations.
b. . . . procedures for determining heptane plus content of small gas samples for use in recombination and analysis of condensate fluids.
c. . . . correlation of electrical resistivity of cores with their brine content.
d. . . . correlation of the electrical characteristics of saturated fresh core samples as related to measurements taken on restored state samples.

XI. Core . . .

a. . . . analysis identification of solid and semi-solid hydrocarbons, which by present methods of analysis are not distinguishable from crude oil.
b. . . . flushing and contamination during cutting and withdrawal.
c. . . . fluid content changes during collection and prior to analysis, including the effect of evaporation, bacterial action, oxidation and other chemical changes.
d. . . . measurements of effective porosity and permeability in tight or fine grained reservoir rocks.

XII. Corrosion . . .

a. . . . protection by use of amine solutions to sweeten gas.
b. . . . protection by use of alloys, linings, and inhibitors.
c. . . . resulting from presence of bacteria.
d. . . . inhibitors for use with high temperatures.
e. . . . rates and inhibitor action as affected by viscosity and linear flow velocities.
f. . . . constituent removal from engine exhaust gases so they can be used in fluid injection operations.
g. . . . rates as affected by water to oil ratios.
h. . . . under scale, its cause and method for inhibiting.

XIII. Drilling Mud . . .

a. . . . interaction with cement at high temperatures and pressures.
b. . . . replaced by a foam or air alone.
c. . . . additives to prevent lost circulation.
d. . . . additive to shut off water zones.
e. . . . physical and chemical properties as they are affected by aging at temperatures of 100° to 400°.
f. . . . mechanism of viscosity control by tannins and polyphosphates.
g. . . . mechanism of water loss control by starch and carboxymethylcellulose.
h. . . . viscosity reducing chemicals as affected by temperatures and pressures.
i. . . . lubricity characteristics as affected by various additives.
j. . . . flow properties as affected by lost circulation materials.
k. . . . properties, salt water base, as affected by carboxymethylcellulose and starch.
l. . . . filtration rates as they affect drilling time.
m. . . . of the oil emulsion type, simulation of wall cake test.
n. . . . oil base and water base, effects on wellbore productivity.

XIV. Cement . . .

a. . . . plugging agents for combatting lost circulation.
b. . . . with retarded setting time.
c. . . . with light weight and low water loss characteristics.

XV. Well Logging . . .

a. . . . methods for determining in place permeability profile of oil sands and limestones.
b. . . . interpretations as determined by a study of the natural electrical characteristics of formations as related to logging resistances, potentials, etc.
c. . . . interpretation for predicting productivity of oil, gas and water from the various formation measurements.

XVI. General

a. Electro deposition of asphaltic solids in reservoir rocks.
b. Determining the presence of bacteria in muds.
c. Mathematical analysis of fluid fingering or bypassing in recycling or fluid injection operations.
d. Study of surface pressure data on a regional scale leading to conclusions regarding:
   (1) Regional migrations of fluids.
   (2) Tilted water tables.
   (3) Pressures in aquifers adjacent to depleted oil fields.
   (4) A possible solution to the cause of abnormal pressures in an oil province.
e. A comparison of the efficiency of gas, electric, or diesel engines used in pumping operations.
f. Electric analogues for study of sucker rod operating characteristics.
g. Recovery of fresh water from salt water.
h. Trace elements in crude oil.
i. Pulsating flow in pipes. ★★★

SUCCESS STORY—ABILENE STYLE

VIRGINIA B. DAGGETT | ASSISTANT SECRETARY PETROLEUM BRANCH, AIME

There is often a story behind routine statistical reports, which is not revealed in columns of figures and percentages. The West Central Texas Local Section of AIME, winner of 1954 membership contests of both the Petroleum Branch and the Institute, recently created such a story.

During the first week of December, Dalton Moore, Jr., section chairman, asked the Branch office how the section stood in the contest, for announcement at its forthcoming dinner-dance. At that point the section had secured 30 applications during the year, showing a percentage increase of 31.3 and a slim lead in the contest.

Within the next week the Mississippi Local Section, a strong contender throughout the year in contest standings, sent in 18 applications, giving them a 70 per cent total increase. Judging from records of previous years and the standings of other sections at that time, this practically assured Mississippi of winning the contest, which is based on applications received as a percentage of Jan. 1 membership.

A few days later Chairman Moore called us for a new contest report. We wished to avoid influencing the contest in any way from the Branch office, but we concluded that we were obligated to report the contest standings to any group interested enough to seek them out. We would have given the same information to any other section requesting it.

Figures reported to the Abilene-headquartered group at this time indicated that about 30 more applications would be required for them to win the contest, with only two weeks remaining in the year. This was more than many sections had secured all year, and might have been discouraging from the section's point of view.

The will and ability of the section's membership was not to be underestimated. Upon hearing the figures, the chairman reflected, "We'd better try for 45." The decision to "go for broke" was made at a directors meeting that same day. Section members at large responded to the enthusiasm of the officers, with the incentive of a 16-mm projector which was to be awarded the winning section. In the last two weeks of the year section members secured 59 applications for membership, giving them a total for the year of 99 and more than doubling their membership, with 103.1 per cent increase.

These applications were a substantial contribution toward putting the Petroleum Branch over its goal of 900 new members for the year. Even more significantly, they demonstrate the potential membership that exists and how it can be developed by individual members working within the local sections.

Membership growth of other local sections during 1954 is not to be overlooked. Second place was won by the Mississippi Local Section, which secured 36 applications for a 78.3 per cent increase. The Denver Petroleum Section placed third, with 31 applications and 34.8 per cent increase. All sections contributed to the final figure of 930 Petroleum Branch applications for the year. This compares with 691 applications during 1953, a 34.6 per cent increase.

Remarkable growth was shown also by several of the new local sections formed during 1954. The Panhandle Local Section was winner of a $100 cash prize in a separate contest conducted for these new sections. The section submitted 38 applications for an increase of 152 per cent since its establishment on April 8.

A complete report on section standings, which space does not allow publishing here, was sent to each local section.

Proposed for Membership, Petroleum Branch, AIME

TOTAL AIME membership on Nov. 30, 1954, was 21,692; in addition 2,011 Student Associates were enrolled.

PETROLEUM BRANCH ADMISSIONS COMMITTEE

F. G. Prutzman, chairman: J. H. Sullivan; F. C. Kelton; C. C. Harter; Virgil Harris; Charles Hudson.

The Institute desires to extend its privileges to every person to whom it can be of service, but does not desire as members persons who are unqualified. Institute members are urged to review this list as soon as possible and immediately to inform the Secretary's office if names of people are found who are known to be unqualified for AIME membership.

In the following list C/ means change of status: R, reinstatement; M, Members; J, Junior Member; A, Associate Member; S, Student Associate.

California
Long Beach — Pollock, James Vawter (R, C/S-S-J).
Sepulveda — Hendrix, James Willard (M).
Taft — Gallear, Darrell Curry (J).
Walnut Creek — Goodwill, David (C/S-A-M).
Whittier — Aker, Jimmie Rollen (C/S-A-J); Newman, James Lee (C/S-A-M).

Illinois
Carmi — Fullop, Paul (C/S-A-M).
Centralia — Martin, Paul James (J).
Flora — Harcourt, George Kenneth (C/S-J-M).
Mt. Carmel — Davies, David Christopher (J).

Kansas
Great Bend — Anderson, Ted C., Jr. (J); Douglass, Jack Lee (J).
Liberal — King, William Roy (M).
Pratt — Evers, Raymond Barney (J).
Wichita — Harwood, Warren Kenneth (C/S-A-M).

Louisiana
Lockport — Decker, Robert Martin (M).
New Orleans — Elderkin, Lawrence William (M); Liston, Perry Aubrey (A).
Shreveport — Coffield, Joe Martin (C/S-A-M); Muirhead, David Aller (M).

Mississippi
Laurel — Kemp, William Madison (A).

Montana
Billings — Ambler, Harold Leon (M); Anderson, Maurice Cooper (J); Autry, Mark Paul (M); Schurtz, Francis Andrews (M).

New Mexico
Hobbs — Disch, John Adrian (J); Peacock, Douglas Rex (J); Scott, Robert Philip (J).

New York
Schenectady — Suits, Chauncey Guy (M).

North Dakota
Grand Forks — Towse, Donald Frederick (C/S-J-M).
Williston — Riethmiller, Donald (J).

Oklahoma
Oklahoma City — Hankowsky, John S. (M); Jones, Tom Temple (R, M).
Ponca City — Alani, Ghalib H. (C/S-A-M).
Shidler — Austin, Homer D. (M).
Tulsa — Franz, Fayette Leland (J); Groeneman, Austin R. (J); Lamberton, William John (M); McCaslin, Leigh Spires, Jr. (C/S-A-M); Taylor, Albert William (M).

Pennsylvania
Bradford — Landers, David Edgar (C/S-A-M); Newton, Richard R. (C/S-A-M).

Rhode Island
Providence — Zussman, Hyman William (A).

Texas
Abilene — Hunter, J. C., Jr. (M).
Amarillo — Richardson, Joseph Chambers, Jr. (J).
Athens — Pool, Ray Ernest, Jr. (C/S-S-J).
College Station — Amyx, James William (C/S-A-M).
Corpus Christi — Goodson, William Clyde (M); Jordan, John Lewis (M); Moeller, Lester Kenneth (C/S-J-M); Wilbanks, Hugh, Jr. (M).
Dallas — Edwards, Robert Bruce (J); Granville, Earnest Bevil (C/S-A-M); Grissom, Pinkney, Jr. (C/S-A-M); Kimbler, Oscar Kavanah (C/S-A-M); Trout, Kye Omri, Jr. (R, M); Tucker, Charles William (C/S-A-M); Watson, John Windle (A); Wood, Samuel Oscar, Jr. (C/S-J-M).
Fort Worth — Bond, Lewis H., Jr. (C/S-A-M).
Hawkins — Taylor, Roland D. (J).
Houston — Davis, William Henry (M); Kirkpatrick, Charles V. (C/S-A-M); Lipson, Leonard Berger (C/S-J-M).
Midland — Courter, Clay N. (M); Knight, Eugene Merritt (M).
Odessa — Russell, Jack Richard (A).
Pampa — Savary, George Anthony (J).
Post — Willingham, Carlton Walker (J).
Rockport — Geffs, Charles Ralph (C/S-A-M).
Tyler — Boutwell, William Bryant, Jr. (M); Clark, William Howard (M); Cotton, James Martin (M).
Wichita Falls — Balch, Sinclair (C/S-A-M); Canan, Thomas Clinton (M); Lewis, Roger Ernest (J); Speer, Lynn Dale (R, C/S-S-J).

Wyoming
Casper — Garthwaite, Delbert Lee (M); Harvey, Thomas Bray, Jr. (J); Zagar, Frank Stanley (C/S-A-M).
Riverton — Horne, Jesse Derward (A).
Rock Springs — Fisher, Sylvester James (C/S-A-M).

Canada
Virden, Manitoba — Cleland, Noel Alfred (J).

Venezuela
Barcelona — Chase, Donald (M).
Caracas — Staub, Harrison Lee (C/S-A-M).
El Tigre — Brown, Harry DeArmon (M).

PERSONALS

JOHN J. ARPS has been appointed vice-president in charge of the Economics and Evaluation Dept. of The British-American Oil Producing Co., Dallas. The native of the Netherlands was graduated from Technical University of Delft, Holland in 1932. He worked in Eastern Europe, the Far East, South America, and the United States with another oil company before joining British-American in 1940 as district engineer for their Gulf Coast area. He has contributed to the technical literature in several fields.

☆

CHARLES F. HUNKINS has been appointed manager of geology and engineering of the Oil Development Dept., Northern Pacific Railway Co. The petroleum engineering graduate of the University of California has been district superintendent for a independent producing company prior to joining Northern Pacific in Billings as chief engineer in 1952.

☆

EDWIN P. OGIER has opened offices in Shreveport as an oil and gas industry petroleum consultant. The firm, located in the Johnson Building, will specialize in geological reports, reserve estimates and appraisals, regulatory commission hearings, and reservoir engineering. Ogier has been a partner in the W. C. Spooner firm of Shreveport prior to the opening of this office.

☆

J. ED WARREN, of The National City Bank, New York, has accepted appointment as a member of the task force for President Eisenhower's special cabinet committee on energy supplies and resources policy. The former deputy petroleum administrator for defense will represent the American oil industry on the three-man task force.

Two AIME members have recently been promoted in the Humble Oil and Refining Co.'s organization. R. J. SCHILTHUIS has been named assistant manager of the Production Dept., Houston, in charge of natural gas production, casinghead gas plants, and gas transportation. He will also coordinate all sales of natural gas. JOHN G. YEAGER, gas superintendent, Louisiana Division, will be acting assistant division superintendent of the Gas Division for a six-month training assignment.

☆

T. B. COUNSELMAN, an AIME vice-president, has joined the firm of Behre Dolbear and Co. of New York, mineral consultants in mining, geology, metallurgy, and management. For the past 27 years he has been with The Dorr Co., Engineers, of Stamford, Conn. A member of the Executive Committee of the Board of Directors, he has held office as chairman of both the Chicago and New York AIME sections and has served as vice-chairman of the Iron and Steel Division and chairman of the Milling Methods Committee.

☆

JAMES D. HUGHES, general sales manager and director of Lane-Wells Co., has been made a vice-president. He is also vice-president and director of Lane-Wells Canadian Co. and a director of Well Surveys, Inc. of Tulsa. He joined Lane-Wells in 1941 and was Gulf Coast division sales manager in Houston. In 1945 he was transferred to Los Angeles in the position of sales manager.

☆

GEORGE C. HOLLINGER has recently been promoted to the position of assistant chief engineer of The Carter Oil Co. in Tulsa. He formerly was located in Shreveport serving in the capacity of division engineer with Carter.

RICHARD A. MORSE has accepted the position of associate director of research with the Gulf Research & Development Co., Pittsburgh. He formerly was reservoir engineering research section supervisor at Stanolind Oil and Gas Co. He received his BS in petroleum engineering from University of Oklahoma and his MS from Pennsylvania State University.

☆

JAY P. SIMPSON has been appointed manager of Gulf Coast Sales and Service Laboratory of Baroid Division, National Lead Co. He formerly was supervising the work of this department and was responsible for Baroid's drilling mud technology training program. He is a graduate in chemical engineering from Rice Institute and has worked for Baroid since 1946.

☆

TRUMAN BRANSCUM, president of the Petroleum Engineering Club, an AIME affiliate society at Oklahoma A&M, was recipient of the Socony Vacuum Scholarship in Engineering for the Fall Semester, 1954. Branscum was graduated in January, 1955, with a degree in petroleum engineering. He has an A- average in college and is a member of Sigma Tau.

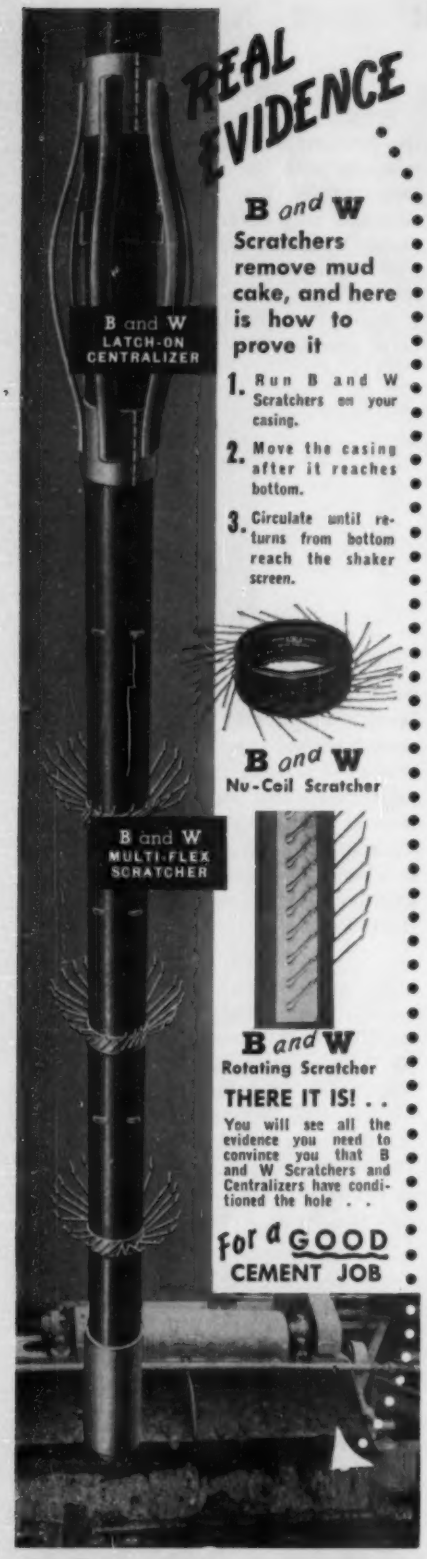
☆

C. R. OLSON, JR., sales engineer for Dowell Incorporated, has opened a new office for Dowell in the Fidelity Union Bldg., Dallas. Olson, who has been with Dowell since 1947, transferred to Dallas from the Oklahoma City office. ★★★

Necrology

Vernon Arthur Gilles, 68, noted Billings geologist, died recently. He was a graduate in mining engineering of the University of Oregon. Since April 1940, he had been chief geologist for the Northern Pacific Railway Co. with headquarters in Billings. He was elected to the AIME in 1917.

Date Elected	Name	Date of Death
1948	M. B. Willey	Unknown
1923	Silas L. Gillan	Nov. 9, 1954
1945	Lawrence Vander Leek	Unknown
1953	John E. Wilcox	Unknown


REAL EVIDENCE
B and W LATCH-ON CENTRALIZER
B and W MULTI-FLEX SCRATCHER
B and W Scratchers remove mud cake, and here is how to prove it
1. Run B and W Scratchers on your casing.
2. Move the casing after it reaches bottom.
3. Circulate until returns from bottom reach the shaker screen.
B and W Nu-Coil Scratcher
B and W Rotating Scratcher
THERE IT IS! . .
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Well Completion Specialists
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Box 5266
Houston 12, Texas
Phone WE-6603
WEST COAST
Box 3751
Los Angeles 54, Calif.
Phone PL-6-9101

MEET the AUTHORS

FRANK W. JESSEN received his BS, MS and PhD degrees from the University of Texas. From 1933 until 1944 he was supervisory engineer of Humble's Production Service Laboratory. During 1944 and 1945 he worked with Petroleos Mexicanos in Mexico City. He then returned to Houston to work as a consultant and with Associated Engineers, Inc. Now he is professor of petroleum engineering at the University of Texas.

JOHN C. MILLER received a BS degree from Stanford University in 1951 and a MS degree from The University of Texas in 1953, both degrees in petroleum engineering. He is presently a junior petroleum engineer for the Stanolind Oil and Gas Co.

BOBBY L. LANDRUM received his BS and MS degrees in physics at A and M College in 1949 and 1950. He is now associated with the Texas Petroleum Research Committee and is engaged in work on heterogeneous and fractured reservoirs.

PAUL B. CRAWFORD received his BS from Texas Technological College and his MS and PhD degrees in chemical engineering from the University of Texas. Prior to accepting his present position in 1952 as assistant director of Texas Petroleum Research Committee, he worked with American Cyanamide and Chemical Corp. and Magnolia Field Research Laboratories.

GENE E. ROARK, vice president of James A. Lewis Engineering, Inc., received his degree in petroleum engineering from Tulsa University in 1942. He joined the Atlantic Refining Company's petroleum engineering department in 1943 and was assistant supervisor in the reservoir engineering section at the time he accepted his present position with Lewis Engineering in 1951.

J. D. LINDNER, petroleum reservoir engineer for James A. Lewis Engineering, Inc., received his BS in physics from the University of Kentucky in 1948. After a short period as a well logging engineer, he went with Lewis Engineering. Since 1951 he has been working as reservoir engineer.

JOSEPH E. WARREN received his BS in petroleum engineering from the University of Pittsburgh in 1951. After working in the Research Dept. of Stanolind in Tulsa he enrolled in Pennsylvania State University in 1952 and completed requirements for his MS degree. Now he is working towards his PhD and holding a Continental Oil Co. fellowship. During a portion of his master's program, he held a Stanolind fellowship.

JOHN C. CALHOUN, JR., received his BS, MS, and PhD degrees in petroleum and natural gas engineering from Pennsylvania State University. He was employed at Penn State from 1937 to 1946, then went to the University of Oklahoma as chairman of the School of Petroleum Engineering. In 1950 he returned to Penn State as head of the Dept. of Petroleum and Natural Gas. In addition to his consulting work and his publication of some 50 technical papers, he has authored a book entitled *Fundamentals of Reservoir Engineering*.

RICHARD L. PERRINE is now project leader engaged in well stimulation research in the Oil Field Research Div. of the California Research Corp. Prior to joining Cal Research in 1953, he was graduated from San Jose State College and Stanford University, receiving his MS and PhD in physical chemistry.

Montana Mines Forms New Petroleum Society

A Petroleum Section of the Anderson-Carlisle Technical Society has been formed at Montana School of Mines in Butte. J. Sherrold Moore is president of the new section, and D. H. Harnish, Jr., assistant professor of petroleum engineering, is the sponsor.

The reorganization of the Anderson-Carlisle Technical Society has resulted in the formation of a unique student chapter plan which is similar to the branch structure of the AIME. Three sections were formed to function under the Anderson-Carlisle Society, a mining section, a petroleum section, and a metallurgical section.

The proposal to reorganize in this manner was formulated and recommended by the petroleum engineering students to the Anderson-Carlisle Technical Society, which accepted it and rewrote the constitution to allow the plan to be put into operation.

Illinois Waterflood Operations Covered by Interstate Pamphlet

The Interstate Oil Compact Commission announces the publication of a new pamphlet on waterflood operations for the State of Illinois. Copies may be obtained by writing to the Headquarters Office, Box 3127, Oklahoma City 5, Okla.

"Summary of Waterflood Operations in Illinois Oil Pools During 1953" is a project of the Illinois State Secondary Recovery and Pressure Maintenance Study Committee, the Illinois State Geological Survey, and the Secondary Recovery Division of the Interstate Oil Compact Commission.

This report supplements four previously issued reports of waterflood operations in Illinois.

Petroleum consultants are finding that professional cards published in the JOURNAL OF PETROLEUM TECHNOLOGY carry prestige and attract business. This professional card space is available to AIME members only. Adv.

Kansas Local Section Holds Symposium On Formation Fracturing

A Symposium on Formation Fracturing was presented by the Kansas Local Section and sponsored by the Kansas Geological Society and the Kansas Independent Oil and Gas Association in December. The meeting, held in Wichita, featured two research papers and approximately 250 persons attended.

"Estimated Production Rates and Waterflooding Recoveries from Commercially Fractured Reservoirs" was presented by R. E. Collins, Stanolind, and Paul B. Crawford, Texas Petroleum Research Committee. Calculated results and model studies showing the effect of the length and number of vertical fractures on well production capacities were given in this paper. Other information presented was: production rates expected from non-linear or crooked fractures under varying pattern conditions; a comparison made of the flooding break-through times of horizontally fractured thin reservoirs prior to and after fracturing; and the effect on sweep efficiencies.

"Development and Application of Vertifrac" was the paper given by Henry F. Coffer, Continental Oil Co. He explained the development of Vertifrac, which fractures vertically by using a non-penetrating fluid such as oil base mud. Covering field tests, he stated that the average increase in production has been from three to six-fold.

An hour and one-half panel discussion followed these presentations. Panel members were: Collins; Coffer; Frank Kaul, Halliburton; S. R. West, Dowell; and James R. Paul, moderator, Dowell.

BACK VOLUMES AVAILABLE

Copies of Petroleum *Transactions* Volume 195 covering 1952 and of Volume 5 covering 1950 of *Statistics of Oil and Gas Development and Production* are available through the Petroleum Branch office in Dallas.

SOUTHWEST TEXAS SECTION PLANS STUDY GROUP MEETINGS

The Southwest Texas Local Section has organized a Study Group which will meet each month at 5 p.m. preceding the regular local section meeting. The first of a series of sessions on completion and production practices was held on Feb. 16 and featured a discussion of "Fracturing in the Frio Formation."

The second Study Group meeting will be held at 5 p.m. on March 16, prior to the Local Section meeting. "Fracturing in the Wilcox Sand" will be the topic for study at the meeting which will take place in Wilson Tower, Corpus Christi, in the Humble Oil and Refining Co.'s conference room.

The nine-man committee which is handling plans for the Study Group is composed of: Don D. Lewis, chairman, Crutchfield & Pruett, Corpus Christi; R. H. Denman, Southern Minerals, Corpus Christi; R. C. Granberry, Jr., Humble, Corpus Christi; Lester K. Moeller, Stanolind, Corpus Christi; Joe A. Peery, Sunray Oil Corp., Corpus Christi; Dick Person, Pan-American, Clarkwood; C. A. Sullins, Union Producing Co., Beeville; Ivan Tucker, Atlantic, Corpus Christi; and George S. Wilson, Magnolia, Alice.

STUDY GROUP IN DALLAS PLANS SPRING SESSIONS

The schedule for the Spring Study Group Meetings of the Dallas Local Section has been released. They will be held at 7:30 p.m. in the Fondren Science Building, Southern Methodist University. General subject for the series is "Reservoir Principles and Reservoir Engineering."

On Feb. 3, W. L. Horner and other representatives of Core Laboratories talked on "General Reservoir Mechanics and Principles." Specific subjects covered were: reservoir forces and controlling factors; properties and characteristics of reservoir fluids and rocks; and problems in fluid movement and recovery.

Gladstone Stewart, of DeGolyer and MacNaughton, will speak on "Principles and Mechanics of Gas Drive Reservoirs" on March 3. On April 7, J. J. Arps, vice-president of British-American Oil Co., will talk on "Principles and Mechanics of Complete Water-Drive Reservoirs."

The May 5 meeting will feature a speaker from the Atlantic Refining Co. "Principles and Mechanics of Gas and Gas-Condensate Reservoirs" will be the subject of this meeting.

Production Histories Booklet Published

Using information from the Petroleum Branch's publication of *Statistics of Oil and Gas Development and Production* through 1952 and additional facts from the Texas Railroad Commission, the Second National Bank of Houston has published a 52-page study entitled "Production History of the Principal Oil Producing Formations in Arkansas, Louisiana, Mississippi, New Mexico, and Texas."

Production history is given for 18 principal oil producing formations in the five state area. Recovery in barrels per acre and barrels per foot are presented on each field. The study can be obtained by writing P. O. Box 2629, Houston 1, Tex.

TWO-DAY PETROLEUM MEETING SCHEDULED for MAY 26-27 by ROCKY MOUNTAIN SECTIONS

A major petroleum meeting has been planned by AIME sections in the Rocky Mountain area for May 26-27, 1955. The two-day Joint Meeting of Rocky Mountain Petroleum Sections will be held in the Shirley Savoy Hotel, Denver.

The Denver Petroleum Section, the Billings Petroleum Section, and the Wyoming Local Section are cooperating in arranging this meeting. Tentative plans indicate that the meeting will be organized so as to attract and accommodate several hundred persons and will be staged in a manner similar to the Petroleum Branch Fall Meeting.

Papers are now being solicited for presentation at technical sessions, and preprints of them will be prepared by the Petroleum Branch office in Dallas. Exhibit space, registration, and entertainment functions are planned.

Committee chairmen for the meeting are: R. L. Hoss, Midwest Oil Corp., general chairman; W. E. Bryan, The Texas Co., Arrangements; John W. Tynan, Continental, Program; R. S. Cooke, Union Oil Co., Housing; R. W. Snead, Eastman Oil Well Survey Co., Exhibits; E. A. Polumbus, Jr., consultant, Entertainment; Billy F. Burke, Carter, Registration; and Gordon Jackson, Eastman, Finance and Publicity.

1955 BRANCH FALL MEETING

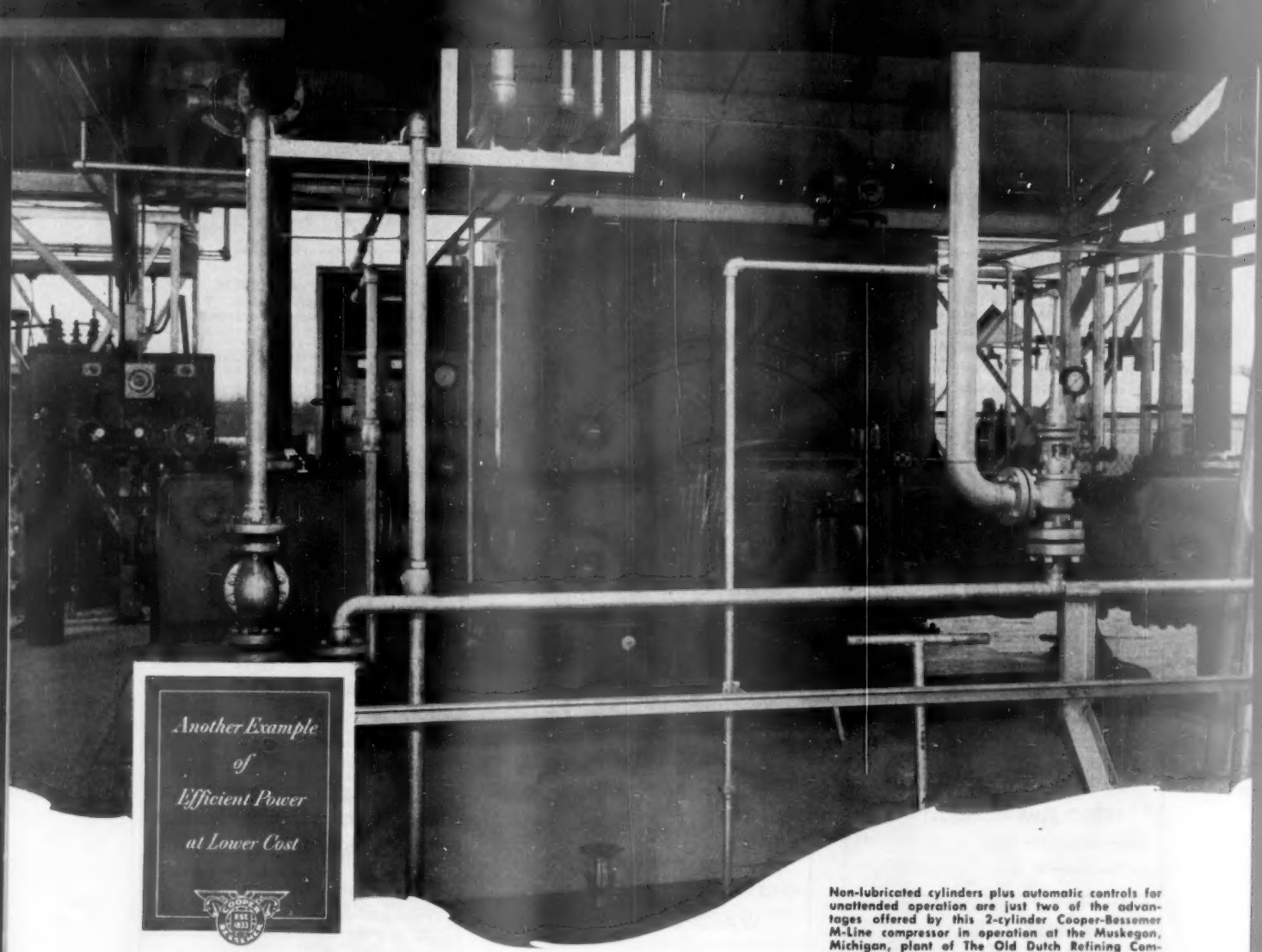
(Continued from Page 23)

and vice-chairmen to be responsible for Fall Meeting activities. They are, with the chairman listed first, followed by the vice-chairman: Arrangements Committee, A. L. Vitter, Jr., The California Co., and Harold Winham, Shell; Entertainment Committee, W. B. Vice, Southern Technical Service, Inc., and W. H. Ashby, The California Co.; Finance Committee, John J. Metzger, Jr., Monterey Oil Co., and Keith J. Ebner, The Texas Co.; and Registration Committee, Charles Doh, Schlumberger, and E. H. Leeman, Shell. Charles A. Capps, Wilson Supply Co., is the chairman of the Housing Committee, to whom all requests for rooms will be mailed after appropriate forms are distributed, and his vice-chairman is Don T. Wise, The Texas Co.

Officers for the Delta Local Section in 1955 who will work directly with the various Fall Meeting Committees are, in addition to B. L. Francis, chairman: B. W. Aulick, Halliburton, first vice-chairman; W. D. Clift, Humble, second vice-chairman; E. H. Leeman, Shell, secretary; Keith J. Ebner, The Texas Co., treasurer; and Fulton Olivier, Humble, Journal secretary. Directors are A. L. Vitter, Jr., The California Co.; R. A. Aucoin, Humble; D. D. Utterback, Freeport Sulphur; Charles Blomberg, The California Co.; Harold Winham, Shell; Max Clayton, Shell; and John Metzger, Jr., Monterey.

With New Orleans as the first class attraction as the convention site, undoubtedly the 1955 Fall Meeting will be one that many members will look forward to attending. Well-planned technical and social programs promise to make this 1955 Fall Meeting an educational experience gained in a holiday atmosphere. R. W. TAYLOR

★★★



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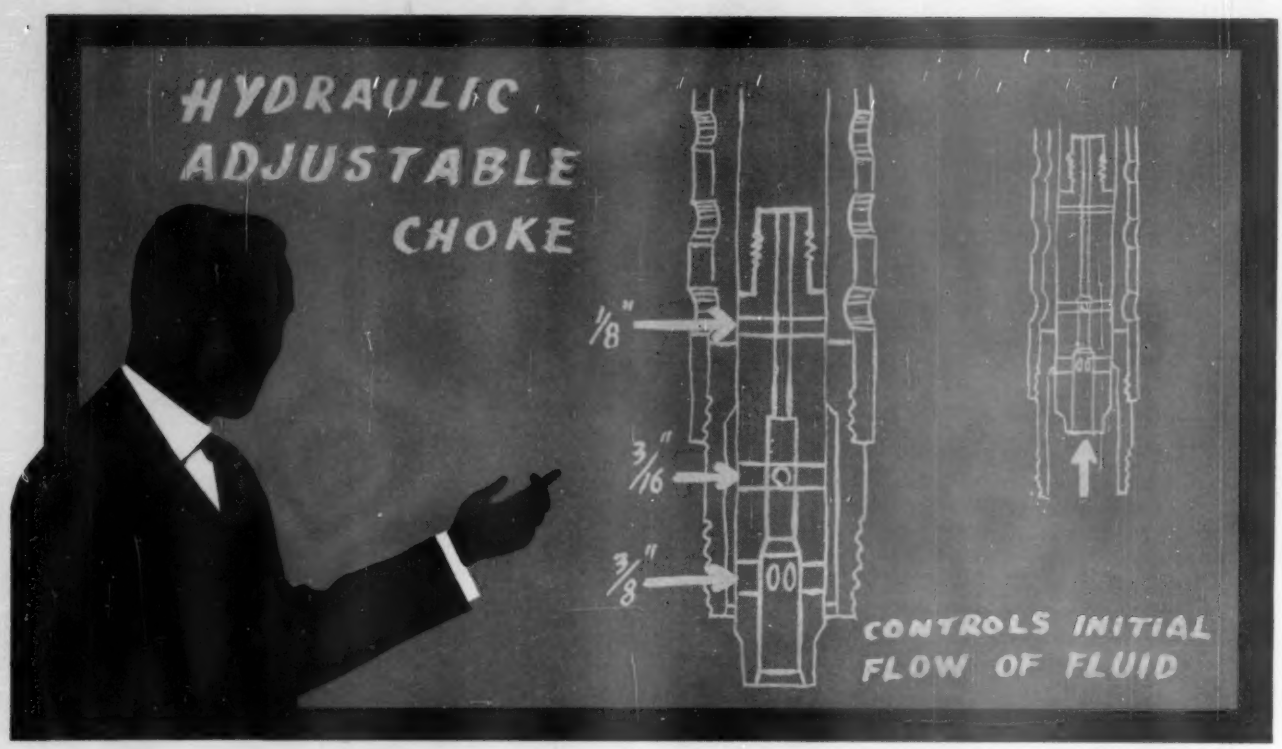

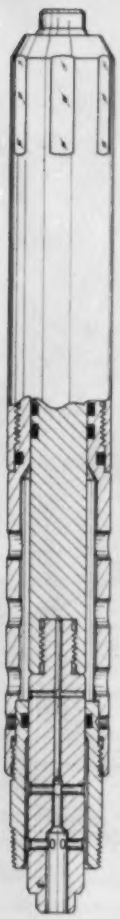

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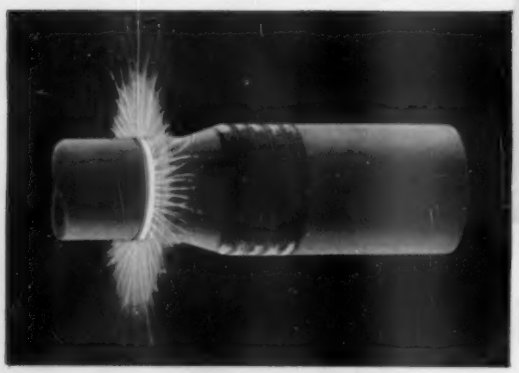

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☆ Petroleum Engineer, 28, with four years' experience in drilling, producing, and reservoir engineering. Now employed with major oil company. Prefers to work in West Texas area. Code 234.

☆ Petroleum Engineer, registered in Texas, desires position with a financial institution. Experienced in reservoir valuation. Engineering degree with 12 years' experience with oil companies. Now with reservoir engineering and valuation company. Married, two children. Code 235.

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☆ Petroleum Engineer, under 35, drilling and production work in Rocky Mountain area with compact but enterprising independent operator with excellent financial structure. Salary dependent upon experience and qualifications. Send detailed experience record. Code 569.

☆ Petroleum Engineer, with MS or PhD in chemistry, mechanical or petroleum engineering, for research and teaching in reservoir mechanics and related fields at rapidly growing southwestern institution. Rank and salary open, 12 months employment possible, consulting work encouraged and available in immediate areas. Applications will be kept confidential. Code 572.

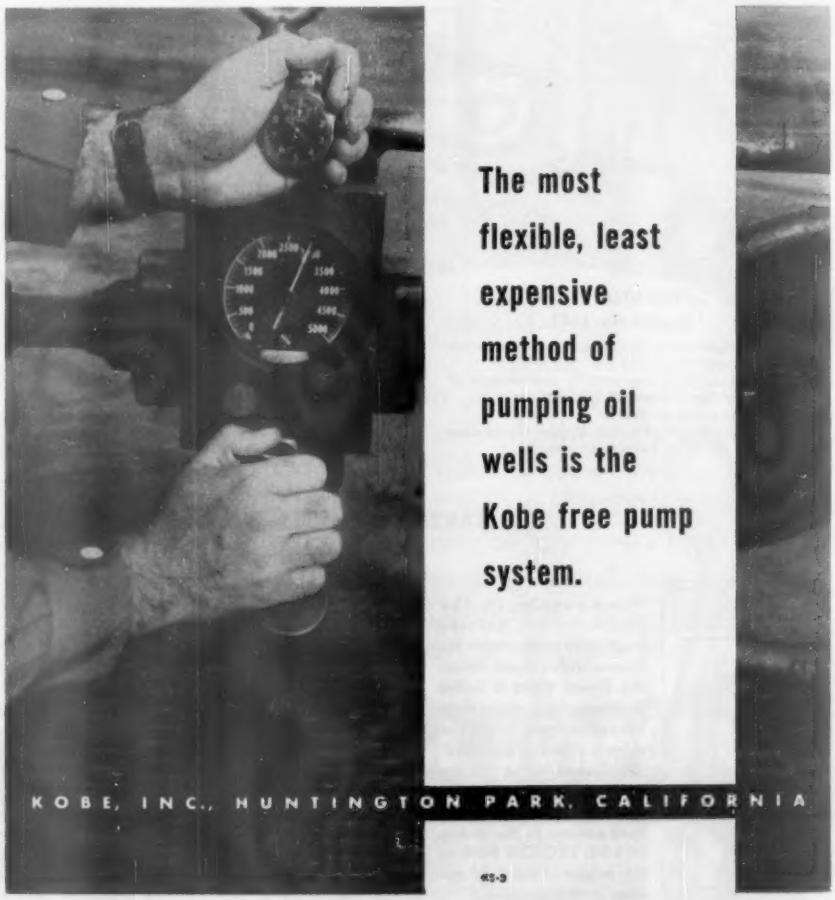
☆ Major Oil Company has openings in New York City and in its foreign operations for graduate petroleum engineers with experience, and for recent graduates in this field to perform engineering work in development, production, drilling, process and oil and gas engineering on primary and secondary recovery. Write giving full particulars regarding personal history and work experience. Code 573.

☆ Petroleum Engineer or Geologist, age 25-32, for reserve estimates, valuation work, analysis oil and gas securities and financial studies. Must be experienced in preparing reports and have ability for original thinking and fluent writing. Location, New York City, with small, rapidly growing professional organization where work load is heavy. Send letter detailing education, experience, work samples (if available) and salary expected. Code 574.

☆ Medium-sized oil company with expanding engineering program has openings for several petroleum engineers with one to three years' experience. Duties will involve production and basic reservoir engineering to include secondary recovery and pressure maintenance operations as well as drilling and workover operations at field and/or district level. Location: West Central Texas. Code 575.

☆ Major university seeks applicants for teaching positions up to and including full professorship. Salary up to $8,500 for the school year depending upon qualifications. Reply giving full details, age, professional experience, academic record, publications, references. Code 576.

☆ Expanding major gas pipe line company with production headquarters located in southwestern Kansas seeks graduate petroleum engineer for work in their reservoir engineering department. Work involves calculating gas reserves, evaluating acreage and preparing economic studies. Code 578.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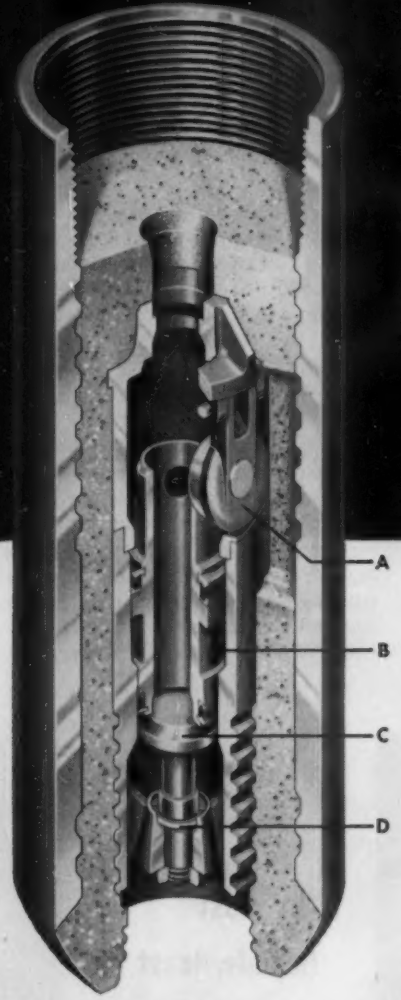

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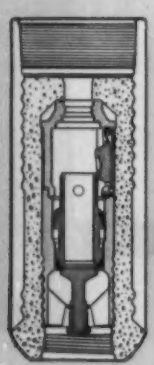
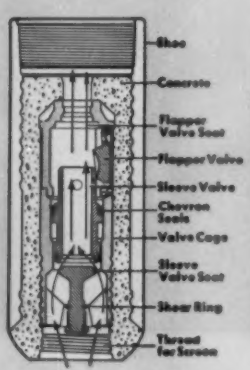
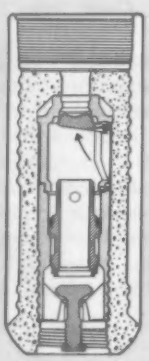


When running-in, the Sleeve Valve is in closed position in contact with the Sleeve Valve Seat. When the Sleeve Valve is in this position, fluid entry into the casing from below the valve is effectively blocked. The Sleeve Valve will be in the closed position whenever the height of the fluid column in the casing (the fill) EXCEEDS 90% of the height of the fluid column in the annulus.



When the height of the fluid column in the casing (the fill) is LESS than 90% of the height of the fluid column in the annulus, the Sleeve Valve moves upward away from the Seat and permits fluid entry into the casing through the bottom of the FILL-UP Shoe. During the casing run, the Sleeve Valve opens and closes according to the pressures imposed on its top and bottom areas and thus automatically regulates the degree of fill.



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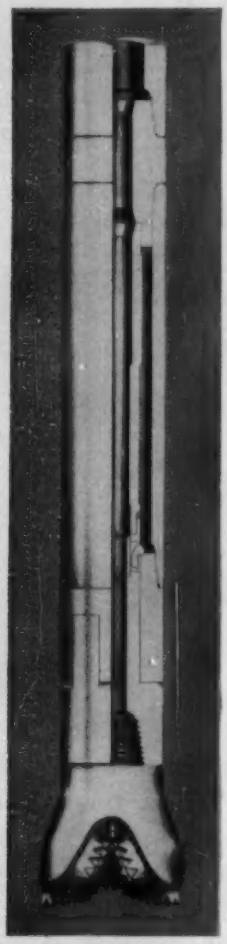

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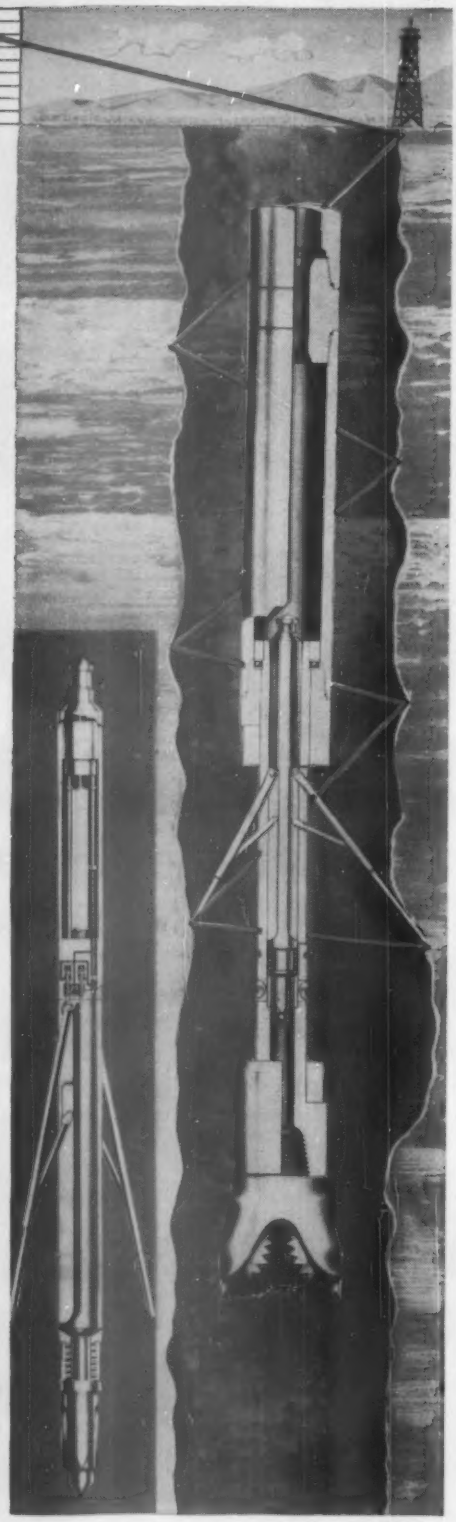

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HC 541

AN INVESTIGATION of the USE of the SPECTROGRAPH for CORRELATION in LIMESTONE ROCK

F. W. JESSEN
MEMBER AIME
JOHN C. MILLER*

THE UNIVERSITY OF TEXAS
AUSTIN, TEX.

BASIC PROBLEM OF CORRELATION

In many areas where carbonate rocks form important parts of the stratigraphic sequence, stratigraphers have experienced varying degrees of difficulty in differentiating and correlating limestone and dolomite units in both surface and subsurface work. With early Paleozoic rocks of the Mid-Continent, insoluble residues yield a remarkable amount of stratigraphic data and relatively good correlations may be carried over broad distances.[1] Unfortunately, neither such information nor electric logs and radioactive logs have been particularly helpful in interpreting the limestone sections of the Permian Basin of West Texas. This is because: (1) the variations in the sections may be very slight; (2) no completely satisfactory method of interpretation has been developed; and (3) the measurements themselves are not sensitive enough for small variations. Also, such logs are influenced by the fluid content.

Paleontology and micro-paleontology remain the ultimate arbiters. As a routine tool, however, paleontological examination is slow and tedious. Chemical analysis may be used, but this, too, is extremely slow. Although rocks are not classified according to chemical composition, there is considerable variation with rock types. Correlation by chemical composition has two advantages, first, the characteristics determined are subject to minimum human error and interpretation, and secondly, the lithologic changes are not masked by fluid content as in the case of electric and radioactive logs. Some fossils concentrate certain elements which tentatively might be used to date rock units.[2]

Rapid chemical analysis by spectrographic means could be used as an adjunct to other means employed in correlation work, or might, in itself, present a suitable method.

PURPOSE OF THIS INVESTIGATION

Sloss and Cooke[3] have published data concerning spectrographic analysis of limestone rocks specifically for purposes of direct correlation of a single formation. These authors found satisfactory evidence that differences in percentage of four elements (Mg, Fe, Al, and Sr) in the Mississippian limestones of northern Montana were useful in carrying out correlation of this formation over a distance of approximately 50 miles. It was concluded from the preliminary work that the spectrochemical method offered possibilities of solution of some problems of correlation heretofore not possible. Since the work of Sloss and Cooke[3] was confined to one particular limestone zone, extension of the use of the method to examine two or more geologic formations would aid materially in the over-all problem of correlation of such rocks.

Equipment is now available commercially with which very rapid spectrographic analyses may be made, and hence the problem was to determine whether the variations existing in the minor constituents of limestones were sufficient for use in possible correlation. Qualitative and semi-quantitative investigations were made to determine whether significant changes in the chemical condition occurred. It was a further purpose to investigate the geologic time-boundaries to see whether significant chemical variation could be found corresponding to the paleontological breaks.

It was desirable to attempt correlation of a thick section of limestone or dolomite rock and to have as much information as possible on the section. Furthermore, it was felt that examination of formations more difficult to correlate by other means would enhance the value of the method should definite points of correlation be found. Samples were chosen from the Chapman-McFarlin Cogdell No. 25 well in the Cogdell field, Kent County, Tex., and from the General Crude Oil Co., Coleman No. 193-2 well in the Salt Creek field, Kent County, Tex. These fields belong to the famous series of "Canyon" reef fields of West Texas. Cores from the above wells were available from the United States Geological Survey, Austin, Tex.

THE SPECTROGRAPHIC METHOD

The choice of procedure to be followed in this investigation was based on the anticipated requirements peculiar to the problem. Since the problem was primarily to investigate the possibilities of applying the spectrograph to problems of correlation in thick carbonate sections, a precise quantitative analysis did not appear necessary. A qualitative analysis to show the possible absence of presence of any element, or a semi-quantitative analysis of the elements present to show the relative changes in magnitude of selected elements was required. Both types of analysis were employed.

The two most widely applied methods of semi-quantitative estimates are those of Harvey[3] and of Slavin[4,5] though various other procedures have been described.[6] While the Harvey method has been modified by Addink,[7] this refinement did not seem necessary to the present problem.

Essentially, the procedure employed is a variation of the total energy method of Slavin with two exceptions: (1) stressing matrix effect, and (2) using densitometer measurements. As measured by a densito-

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[1]References given at end of paper.

meter, the readings on the line will not give line intensity alone, but the intensity of the line plus background, since there is a continuum superimposed over the line itself. Hence, it becomes necessary to correct for the background in order to get a true evaluation of net line intensity or detectability.[8,9]

METHOD OF THIS INVESTIGATION

Samples from the two wells were furnished by the Austin Section, Geological Div., Fuels Branch, United States Geological Survey. Portions of the sampled cores from the Chapman-McFarlin well in the Cogdell field had been crushed for chemical analysis and for acid insoluble residue studies.

SAMPLE PREPARATION

Samples representative of 630 ft of section from the Chapman-McFarlin Well 25 were available in crushed form. Material from each 10 ft interval was mixed together, yielding 63 samples for analysis. About 200 gm of the crushed sample was reduced to about 1 gm by the usual cone and quarter method. It was ground with a small agate mortar and pestle until homogeneity was ensured and the bulk of the sample reduced to about −150 mesh. Although the sample should be reduced to about −150 mesh, it should not be passed through a sieve since the use of ordinary brass sieves may introduce copper, zinc, lead, and tin in detectable quantities.[10] After grinding, the samples were dried for an hour at 105° C. After this they were loaded into small capsules, capped, and placed in a convenient tray ready for analysis.

WEIGHING SAMPLES AND LOADING ELECTRODES

After the samples were powdered, dried, and capsuled, 10 mg were weighed from each vial. A Heusser gold assay balance, sensitive to 1/300 mg, was found to be quite satisfactory. A 10 mg sample of powdered high purity graphite, obtained from cuttings of the graphite electrodes, was weighed and added to the sample and the two were mixed thoroughly. The mixture was then poured into the electrode with the aid of a small spatula and quillbrush.

The loaded electrode was then placed in a desiccator to keep atmospheric moisture from the sample until it was arced in the spectrograph.

Sample No. ____ Film No. ____ Date ____

Ele	Line	Observ	Ele	Line	Observ	Ele	Line	Observ
Cd	2288.0		Sb	2877.9		Cd	3261.1	
As	2288.1		Si	2881.6		Se	3262.3	
Be	2348.6		Bi	2938.3		Sb	3267.5	
As	2349.8		Ge	2943.6		Ag	3280.7	
Be	2494.5		Co	2997.3		Zn	3282.3	
B	2496.8		Fe	3020.6		Mo	3302.3	
Si	2516.1		Ga	3039.1		Ag	3382.9	
P	2535.6		Sn	3067.7		Zr	3392.0	
Hg	2536.5		Be	3071.6		Cd	3403.7	
P	2554.9		Al	3082.2		Co	3407.1	
Mn	2576.1		Cb	3094.2		Ni	3414.8	
Ge	2651.2		Be	3030.4		K	3446.4	
Cb	2716.6		Mo	3132.6		Ga	3453.5	
Mg	2781.4		Mo	3170.3		Sr	3464.6	
Mo	2816.2		V	3185.4		Ti	3653.5	
Pb	2833.1		Li	3232.6		Be	4246.8	
Se	2840.0		Y	3242.3		Cr	4254.3	
As	2860.5		Cu	3247.5				

FIG. 1—QUALITATIVE SPECTROGRAPHIC ANALYSIS DATA SHEET.

SPECTROGRAPHIC METHOD OF ANALYSES

The spectrograph used was a 1½ m unit having a grating of 24,400 lines per inch and was manufactured by Applied Research Laboratories, Glendale, Calif. After arcing of the samples the exposed film was developed under carefully controlled conditions which yielded reproducible clear and sharp spectral lines. After processing, the films were dried in the usual manner and were examined in a densitometer and filed for future reference.

EXAMINATION OF FILMS: QUALITATIVE

Ahrens[10] and others[6,7] have described the elements most likely to be found in limestone rocks. A chart was made arranging the elements in order of increasing wave length to facilitate analyzing the film. Various revisions were made to fit the particular situation.

Some elements (Au, Hf, U, Th, Pt, Os, Pd, Rh, Ir, Ru, W, and others) virtually never are present in detectable amounts; these could most probably be studied best by first employing some chemical means of concentration.

Fig. 1 shows the final form which was used for the qualitative examination. It would probably be suitable for other limestones. Lines of 36 elements were sought. Elements (such as iron, magnesium, and silicon, because of their relatively high concentration and/or their high sensitivity) could easily and positively be identified by one line. In other cases, the elements were less easily identified and two or more lines were examined in order to establish their presence. Elements falling in this group were columbium, berylium, and arsenic.

EXAMINATION OF FILMS: QUANTITATIVE

The method described by Harvey[5] was used in calculating the semi-quantitative values. In the choice of elements on which to make estimates, several factors must be considered: (1) the quantity and/or the sensitivity of the element had to be such that accurate readings could be taken, (2) lines should be free from interference of nearby lines of another element, and (3) the background must be reasonably uniform and have sufficiently high transmission, viz, 80 to 95 per cent.

The only elements, other than those of the main constituent (calcium carbonate), which met these requirements were aluminum, iron, manganese, copper, chromium, magnesium, and silicon. Semi-quantitative determinations were made for all of these with the exception of silicon and magnesium. In the case of silicon, it was felt that no substantial contribution to correlation would be gained by its determination. An evaluation of the magnesium content was not made because the sensitivity factors for suitable lines were not available.

A carefully constructed calibration curve which was available for this research[11] aided greatly the separate determination of the selected elements in each sample.

RESULTS

The results of the qualitative and semi-quantitative analyses are presented in graphical form in Fig. 2. As can be seen, a considerable variation in composition was found throughout the section of each of the two wells studied. In addition to the elements used for correlation, the following elements were found in all samples: Ag, As, B, Be, Bi, Ca, Cb (or Nb), Co, Mg, Na, Si, Sr, Ti, and V.

While the accuracy of the semi-quantitative method is plus or minus 30 to 50 per cent, little inconsistency was evident. This can be seen readily when comparing the relative variations in manganese and iron. Geochemically, these elements occur together and variations in one should be reflected by the other. Such was found to be the case with only a few exceptions. Thus, a usable log can be obtained without resorting to more time-consuming methods to ascertain the magnitude of concentration with high precision. Aluminum, copper, and chromium are less closely related geochemically to iron and

so would not be expected to follow so closely the same trends.

The aluminum content is indicative, to a degree, of the amount of clay or weathered material present. This is especially evident at the base of the Canyon formation found in the Chapman-McFarlin Cogdell No. 25 well. Here, a 60 ft section has been interpreted by the U. S. Geological Survey[12] as being material which has been eroded and redeposited. Such material would be expected to contain a relatively large amount of clays. The high aluminum percentage in the lower part of this zone tends to confirm this supposition. The presence of relatively high percentages of titanium are further evidence in support of this viewpoint.

Chromium seems to be a good "marker" element. It is particularly useful in observing changes in rock.[10] Copper was used to register any other changes which might not be reflected by variations in the other elements.

The reef is generally considered to be entirely of Canyon age. After exhaustive paleontological study, the U. S. Geological Survey determined that the reef was actually a part of three formations, viz, the Cisco, the Canyon, and the Strawn. The division of the reef into these units may also be deduced from the spectrographic analysis.

A rather good correlation is obtainable on the basis of variations in manganese, aluminum, copper, and chromium content. It is to be noted that the percentage of chromium and copper was in the order of magnitude of 10^{-4} to 10^{-5} per cent while that of iron, manganese and aluminum was reported to 10^{-2} to 10^{-3} per cent. At the base of the Cisco (from paleontological studies) there is a decided decrease in all the above elements followed by a sharp increase in concentrations of each at or near the top of the Canyon. Accompanying these changes are marked increases of titanium also. A very definitely correlatable zone occurs midway in the main body of the Canyon section as evidenced again by substantial increases in all five elements.

Although these changes in concentration are not as pronounced in the General Crude Oil Co., Coleman No. 193-2 well, the trend is noticeable. Near the base of the Canyon or top of the section designated as Strawn another good correlation point is apparent. Particularly large increases

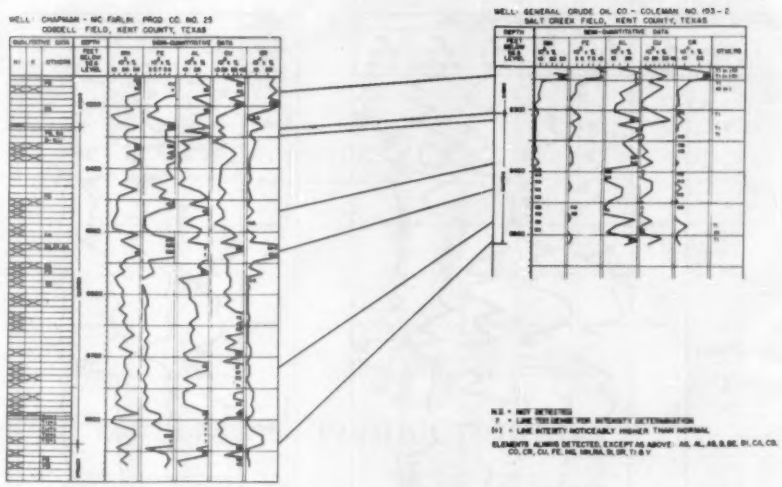

FIG. 2 — RESULTS OF SEMI-QUANTITATIVE AND QUALITATIVE ANALYSES.

of aluminum (with attending increased concentration of titanium), and correspondingly varying amounts of copper and chromium were noticed. Though iron and manganese content of samples from the Chapman-McFarlin Cogdell No. 25 well followed this pattern, no similar increases were observed in the General Crude Oil Coleman 193-2 well. However, the presence of titanium again gave good confirmation to the correlation at this zone contact. The shortened section of the entire geologic section would be considered to affect adversely any correlation, and yet satisfactory comparison can be made.

Such evidence could be of great use since these breaks were not recognizable in other logging methods used on the well. From information secured from the U. S. Geological Survey these breaks were not evident, except by paleontological means, in any part of the reef fields. The average percentage of all five of these elements (Mn, Fe, Cu, Al, and Cr) taken together is about 0.13 per cent. Chemical analyses made by the U. S. Geological Survey indicate that the magnesium content averaged 1 to 2 per cent.

In the qualitative examination, it was found that nickel quite frequently was detectable. Provided the samples had been handled in the same manner, this might possibly indicate the presence or absence of oil, since nickel has been reported by Goldschmidt[13] as characteristically associated with oil. Other elements often associated with oil are vanadium, copper, silver, molybdenum, and tungsten. All but the last two were found to be present. If this relationship is true, then these elements could possibly be used to determine the more highly saturated oil zones.

The method showed that it possessed the necessary sensitivity to chemical changes to be of use for correlation purposes. In fact, the correlations shown in Fig. 2 make it possible to carry out more detailed examination of certain zones within the broader geologic sections.

Fig. 3 and Fig. 4 show the correlation obtainable on each of the wells examined utilizing results of chemical analyses obtained during investigations carried out separately by the U. S. Geological Survey office in Austin. It is immediately apparent that the variations in concentration of the elements detectable by spectrographic analysis and the changes in concentration of the elements most commonly determined follow a rather definite pattern. Two zones of high degree of dolomitization occur in the Chapman-McFarlin well at 6,250 to 6,255 ft and 6,420 ft while lesser amounts of dolomite were determined at 6,358 to 6,363, 6,535 to 6,540 and 6,855 to 6,860 ft. Although these thin streaks of dolomite are not developed in the General Crude Oil Co. well, the changes in composition reflected by the spectrographic analysis help to characterize the corresponding zones in the two wells. It is also interesting to note the rather close agreement in the iron content determined analytically (on the acid soluble residue) and reported by the U. S. Geological Survey study and that obtained by the spectrographic method employed in this investigation.

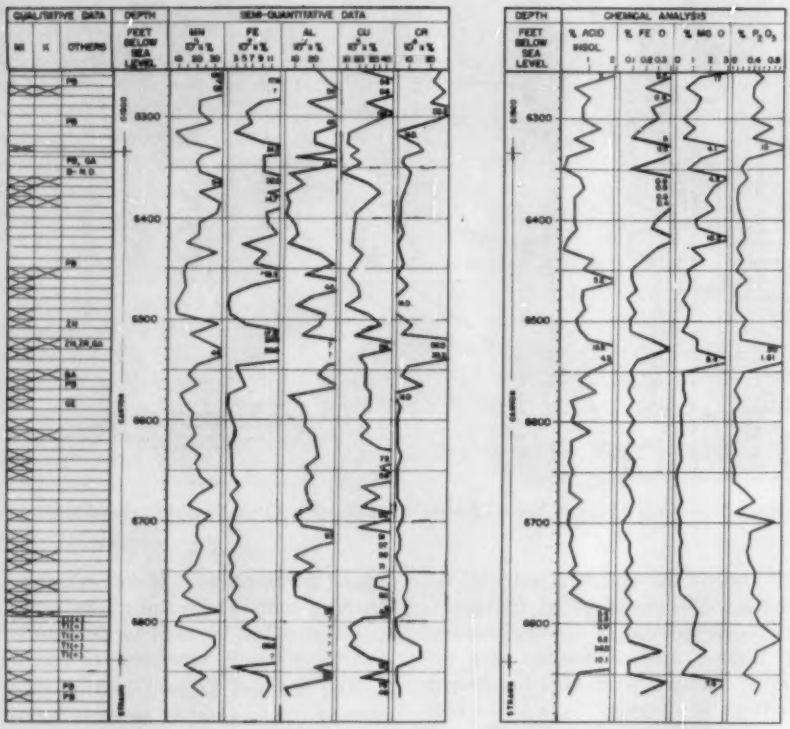

FIG. 3 — CORRELATION OF SPECTROGRAPHIC AND CHEMICAL ANALYSIS, CHAPMAN-MCFARLIN PRODUCTION CO., COGDELL WELL 25.

SUMMARY

Geologic correlation of limestone cores from wells located in two separate Canyon Reef fields of West Texas has been possible by means of spectrographic analysis. Although the present work has been limited to the investigation of carbonate rocks, the method should prove applicable to any type geologic formation.

Rapidity of analysis with improved analytical equipment available should be of tremendous advantage in the routine logging of wells and also in advancing further research in this very important field.

Value of spectrographic analysis in studying various phases of sedimentation is suggested.

ACKNOWLEDGMENTS

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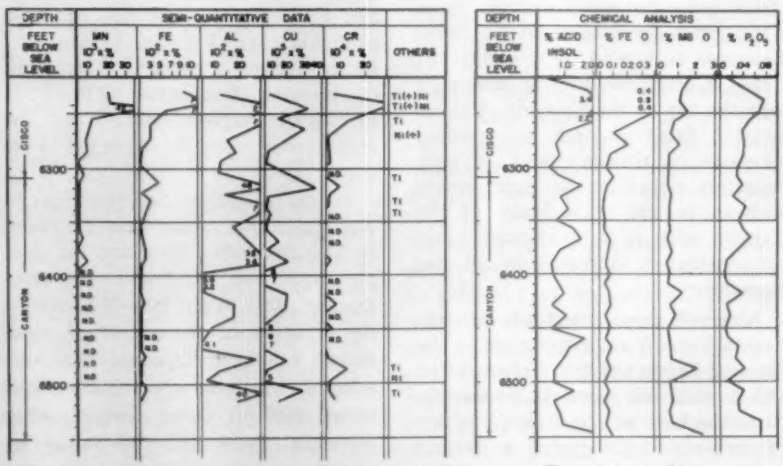

FIG. 4 — CORRELATION OF SPECTOGRAPHIC AND CHEMICAL ANALYSIS, GENERAL CRUDE OIL CO., COLEMAN WELL 193-2.

TECHNICAL NOTE 266

EFFECT of DRAINHOLE DRILLING on PRODUCTION CAPACITY

BOBBY L. LANDRUM
PAUL B. CRAWFORD
MEMBER AIME

TEXAS PETROLEUM RESEARCH COMMITTEE
A&M COLLEGE
COLLEGE STATION, TEX.

ABSTRACT

Electrical model studies have been made of the effect of drainhole drilling on production capacity. Drain holes are those lateral holes which are sometimes drilled to assist in increasing the oil drainage into the main wellbore. The studies indicate that if the drainhole length is near 0.2 of the drainage radius, the increase in production capacity may be approximately 1.8, 2.08, and 2.33 for the case of one, two and four drain holes, respectively. If multiple drain holes are drilled, shorter holes are required to achieve a specific increase in production capacity than if one or two holes are drilled. To achieve increases in production capacities by factors near three it is shown that the drainhole lengths divided by the drainage radii must be approximately 0.64, 0.48, and 0.37 for the case of one, two and four drain holes, respectively.

INTRODUCTION

Recent developments in drilling techniques have permitted the drilling of lateral or horizontal holes to increase the rate of production. The number of these drain holes may vary from 1 to 10, and they have been drilled laterally as much as 100 ft. Drainhole drilling at substantial depths is of recent origin but has been used in the Spraberry field of West Texas, the La Pas field in Western Venezuela, and certain fields in California. The diameter of the drain holes has been approximately 6 in. In drilling drain holes it is desired to know how much increase in production capacity may be expected, what additional benefit may be gained by drilling more than one drain hole, and what increase in production capacity may be brought about by lengthening the existing drain holes. In realization of the importance of lateral drilling, electrical model studies were made to provide quantitative estimates on the effect of drain holes on production capacity.

ANALYSIS

An electrical model was used in studying this problem. A wooden circular reservoir approximately 30 in. in diameter and 2 in. deep was filled with a dilute salt solution to a depth of 1 in. A copper band formed the periphery of the tank, and a copper wire was inserted in the center of the tank to represent the well. The drainage radius divided by the well radius was equal to 500. A diagram of this type model is shown in the inset of Fig. 1. An electrical potential was applied to the wire well and copper band at the periphery to determine the flow of current. Following this measurement copper wires of various length were soldered to the vertical wire well in such a manner as to simulate lateral wells drilled into the reservoir. Multiple lateral holes of various lengths were studied by varying the number and length of copper wires soldered to the vertical wire well. All multiple lateral wells were located symmetrically about the vertical well. The effect on production capacity by drilling an infinite number of lateral holes was studied by replacing the lateral hole with a copper disk. For each condition the flow of current was measured and compared with the flow of the vertical well only.

The model which is thus described provides the steady state increases in production capacity which may be expected in some cases. The data conform to those which would be observed for a uniform homogeneous reservoir. The data may have primary application to those reservoirs producing above the bubble point. It is realized that few lateral holes are drilled in reservoirs of this type, but the data may be of some value in guiding future work or aiding to explain observed phenomena.

Manuscript received in Petroleum Branch office on May 19, 1954.
[1]Reference given at end of paper.

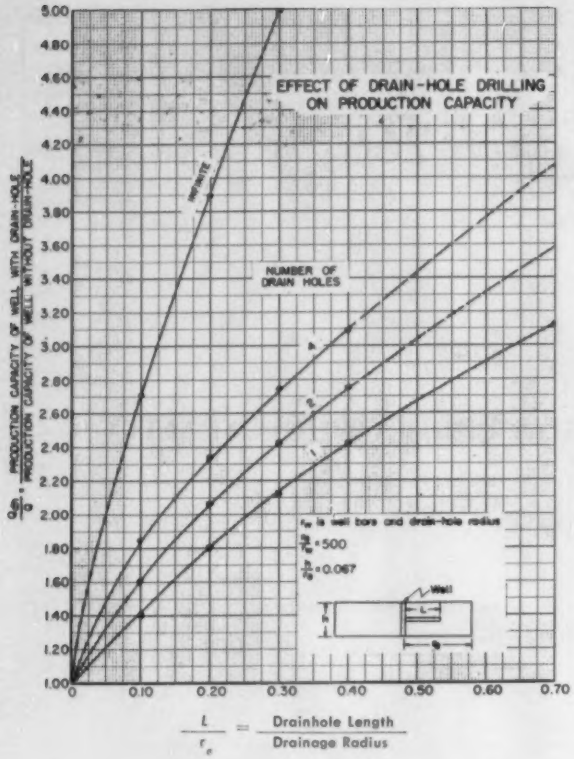

FIG. 1

PRODUCTION CAPACITIES

Fig. 1 shows the effect of drainhole drilling on production capacity. The abscissa shows the length of the drain hole divided by the drainage radius. For example, if the drain hole were 60 ft in length and the drainage radius 300 ft, the value of the abscissa would be 0.2. The ordinate shows the production capacity of the well with the drain hole divided by the production capacity of the well before drilling the drain hole. For example, if the steady state production capacity after drilling the drain hole were 40 B/D and the production capacity prior to drilling were 20 B/D, the value of the ordinate would be 2.00. In reviewing Fig. 1 it will be noted that if the drainhole length divided by the drainage radius is near 0.1 that an increase in production capacity by factors near 1.4 to 2.7 may result, depending on whether one or an infinite number of drain holes are drilled. If two or four drain holes are drilled, increases in production capacities near 1.6 and 1.84 would be expected, respectively.

If the drainhole length is approximately 50 per cent of the drainage radius the expected production capacity increases would be 2.66, 3.04, and 3.45 for the case of one, two and four drain holes, respectively.

If the drainage radius were near 300 ft, it will be found that the drilling of a single drain hole 60 ft in length would result in an increase in production capacity of approximately 1.8. To drill a second hole of the same length would increase the production capacity from 1.8 to 2.04. To drill four drain holes, all symmetrically located about the well and each 60 ft long, would give a production capacity increase of 2.34. If the length of the holes were doubled and the drainage radius remained the same, the production capacity would be 2.4 for one drain hole and 2.74 for the case of two drain holes. Four drain holes would result in an increase in production capacity near 3.08.

Fig. 1 may be used to indicate the length which one drain hole must be drilled to give an increase in production capacity equivalent to two or four drain holes of shorter length. For example, if four drain holes of 0.1 the drainage radius were drilled the increase in production capacity would be approximately 1.85. To obtain this same production capacity with only two drain holes would require lengths of approximately 0.15 of the drainage radius. A single drain hole whose length was 0.21 of the drainage radius would be expected to result in the same production capacity. If this were verified by field data it might be found more desirable in some instances to drill a few long drain holes rather than multiple short holes. Field data have been obtained in some instances to show the effectiveness of drain holes in increasing the production capacity. These data are summarized in Table 1. Table 1 shows a comparison between the actual increase in oil production by drilling drain holes and that which might be estimated from model data shown in Fig. 1. Data are shown for 10 different wells. It will be noted that for the case of two drain holes that increases in production of approximately 2.00 to 2.58 were obtained; whereas, model data obtained from Fig. 1 indicates increases near 1.9 would have been expected.

For the case in which four drain holes were drilled the actual increases were near 1.84 to 3.85; from Fig. 1 it would be estimated that an increase near 2.18 would have been expected. For the case of six drain holes it is shown that increases in production capacity near 1.85 to 3.00 were observed, whereas, the figure would indicate that an increase in production capacity near 2.3

TABLE 1 — SUMMARY AND COMPARISON OF 10 CALIFORNIA DRAINHOLE WELLS*

Well	Depth Ft	Hole Size In	Drain Holes Size, In	Drain Holes No.	Oil Prod., Bbl Daily Init.	Oil Prod., Bbl Daily Settled	Prod. Reported in Nearby Correlating Wells, Bbl Daily	Settled Fractional Increases in Production Capacity Actual	Settled Fractional Increases in Production Capacity Model Data**
1	3700	11	6	2	90	62	24	2.58	1.9
2	3550	11¾	6⅛	2	60	(‡)	25-30		1.9
3	3600	11	6	4	54	+46	25	1.84	2.18
4	3300	10⅝	6⅛	4	80	100	26	3.85	2.18
5	4800	10⅝	6	4	150	(‡)	40		2.18
6	3600	11¾	6⅛	4	93	60	25-30	2.18	2.18
7	3650	9⅝	6⅛	4	95	(‡)	20-30		2.18
8	1200	7⅝	6	6	35	15	5	3.00	2.3
9	3700	6⅛	4¾	6	61	48	26	1.85	2.3
10	3600	11¾	6⅛	8	234	210	70-90	2.62	2.4

* All drain holes equipped with flexible liners. Wells 8 and 9 are located in San Joaquin Valley; all others in Los Angeles basin area[1].
+ Well had been abandoned as noncommercial.
‡ Not reported.
** Actual drain holes were 40 to 50 ft long, all assumed to be 50 ft for comparison with model data. Drainage radius = 300 ft, effective $r_e \div r_w$ = approximately 500.

could be expected. For the case of eight drain holes an increase near 2.62 was observed; Fig. 1 would indicate that an increase near 2.4 would be expected.

In reviewing the comparisons between the actual observed increase in oil production capacity and that indicated by model data it is found that fair agreement was observed in some instances. Inasmuch as the actual observed increase in oil production was only slightly greater than predicted from the model, it should also be mentioned that the present well completion techniques in these wells are apparently of such nature that little damage near the wellbore may be occurring in some instances. Fig. 1 shows the increases in production capacity which may be expected if the wells are clean and no impediment exists near the wellbore. If considerable damage had occurred through mechanical plugging, clay swelling, etc., the variations in production capacity by drilling drain holes may have been much greater than those shown by Fig. 1.

DISCUSSION AND CONCLUSION

Electrical model studies have been made of the effect of drainhole drilling on the production capacity. It is indicated that if the drainhole length is near 0.2 of the drainage radius that increases in production capacity near 1.80, 2.06, and 2.34 may be expected for the case of one, two, and four drain holes, respectively. It is shown that it may be possible to drill one drain hole which will result in a production capacity equivalent to that of drilling two or four drain holes, provided the one drain hole is of the proper length. Comparisons have been made of the effectiveness of drain holes in actual oil wells and compared with the model data presented here. In general the agreement appears to be reasonable. It is also indicated that the present well completion techniques in these wells may be of such nature that little damage near the wellbore may be occurring.

ACKNOWLEDGMENT

The authors wish to acknowledge the encouragement of George H. Fancher, director of Texas Petroleum Research Committee, in conducting the work. William Streiff prepared the illustration. Appreciation is expressed to the Research Committee for permission to publish the results.

REFERENCE

1. Stormont, D. H.: "Increase in Drainage of Oil into Well by Drain-Hole Drilling," *Oil and Gas Jour.*, Aug. 17, 1953, 105. ★★★

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EFFECTS of EXTENSIVE WELL FRACTURING on a WATERFLOOD OPERATION in the NORTH TEXAS STRAWN SAND

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ABSTRACT

Waterflooding operations in the Langston-Kleiner field, Young County, Tex., are described. Widespread application of formation fracturing has been practiced in both producing and injection wells. Field performance data are cited which indicate that no detrimental effect on sweep efficiencies and that probable benefits in injectivity have resulted from the fracture treatments.

INTRODUCTION

This paper is a report on a waterflood operation which is being carried out in the Langston-Kleiner field located in Young County, Tex. The oil reservoir affected by this flood operation occurs in a Strawn sand member at an approximate depth of 3,550 ft subsurface. The operators of the project are Kleiner Estate, Turner, Fiske, and West who are hereinafter collectively referred to as the Operators. Although the operation is unusual in several respects, the distinctive feature of this flood has been the widespread application of hydraulic formation fracturing treatments as a means to improve productivity and injectivity of the wells. It shall be the purpose of this paper to present basic information regarding the reservoir characteristics, operating practices, and waterflood behavior so that conclusions may be drawn concerning the effects which the fracture treatments have had on the performance of this water flood to date.

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Discussion of this and all following technical papers is invited. Discussion in writing (3 copies) may be sent to the offices of the Journal of Petroleum Technology. Any discussion offered after Dec. 31, 1955, should be in the form of a new paper.

DEVELOPMENT

Development of the 3,550 ft Strawn sand reservoir occurred during 1951 and 1952. The early development occurred on the Langston and Davis leases which are in the northern region of the Operators' holdings and the wells were drilled on 20-acre proration units according to the field rules. However, studies of the economics of this program, coupled with the decision to proceed with pressure maintenance by water injection, resulted in the adoption of wider spacing in the later stages of development. This variation in spacing is apparent upon inspection of Fig. 1 upon which only the 3,550-ft Strawn sand producing and injection wells have been located on the Operators' properties. The development to the north of the Operators' leases is the Garvey Strawn field and that to the south is the Taylor Strawn field.

It was determined that unitization of the leases to be involved in the waterflood program was not feasible. Consequently, a system of offset injection wells, or lease line injection wells, was adopted from place to place as required to protect correlative rights in the program. This resulted in a dispersed array of injection and producing wells with relatively close proximity of wells along lease line areas and wider spacing toward

TABLE 1 — SUMMARY OF FRACTURE TREATMENTS IN 3,550-FT SAND RESERVOIR, LANGSTON-KLEINER FIELD, YOUNG COUNTY, TEX.

LEASE AND WELL NO.	COMPLETION INTERVAL	NO. OF HOLES	FRACTURE TREATMENT			SHOT INTERVAL	QUARTS NITRO
			INTERVAL	POUNDS SAND	GALLONS OIL		
DAVIS 15	3495-3507	48	3495-3514	1600	1200		
	3510-3514	16					
DAVIS 16	3478-3498	OH				3478-3498	100
DAVIS 17*	3490-3498	64	3490-3498	1500	1200		
LANGSTON 70	3523-3537	OH				3523-3537	45
LANGSTON 71	3466-3474	32	3466-3486	2500	2500		
	3480-3486	24					
	3515-3527	48	3515-3574	2500	2500		
	3559-3574	OH				3559-3574	45
LANGSTON 72	3517-3533	OH	3517-3533	700	700		
LANGSTON 73	3522-3549	OH					
LANGSTON 74	3485-3520	OH	3485-3520	4000	4000		
LANGSTON 75	3507-3523	OH	3507-3523	5000	5000		
LANGSTON 76*	3526-3566	OH				3526-3576	130
LANGSTON 77	3507-3533	OH	3507-3533	5000	4000		
LANGSTON 78	3472-3482	41	3472-3503	2000	2500		
	3488-3503	61					
	3516-3530	56	3516-3530	1000	1400		
LANGSTON 79	3509-3547	OH	3509-3547	4000	4000		
McKINLEY 33	3493-3512	91	3493-3512	3000	3000		
McKINLEY 34	3459-3466	42					
	3476-3508	OH	3476-3508	3000	3000		
McKINLEY 35	3447-3460	75	3447-3460	700	700		
	3464-3469	16					
	3476-3490	52					
	3492-3506	52					
McKINLEY 36	3498-3512	57	3498-3512	3000	3000		
McKINLEY 37	3478-3492	56	3478-3498	4700	4700		
	3494-3498	16					
McKINLEY 38	3466-3480	88	3466-3480	4000	4000		
	3500-3505	20	3500-3505	1200	1200		
McKINLEY 40*	3512-3518	48	3512-3518	1500	1450		
McKINLEY 41*	3503-3513	OH	3503-3513	3000	3000		
SWEET 14	3469-3502	OH				3469-3502	85
SWEET 15	3454-3475	OH				3454-3475	70
SWEET 16	3442-3445	16	3442-3445	700	700		
	3471-3479	32					
	3488-3494	24					
	3496-3505	36					
	3524-3530	24					
SWEET 17	3460-3474	56	3460-3474	700	1050		
SWEET 18	3443-3452	36	3443-3452	5000	5000		
	3472-3489	OH					
SWEET 19	3472-3484	48					
SWEET 21*	3469-3483	56	3469-3483	2000	2000		
SWEET 22	3480-3495	OH					
SWEET 23	3459-3466	28	3459-3466	6000	6000		
	3507-3515	32					
W. I. 2*	3454-3466	47	3454-3466	3000	2500		
	3488-3521	OH	3488-3521	2000	2000		
W. I. 3*	3458-3470	46	3458-3470	1500	2000		
	3488-3502	OH	3488-3502	1600	1500		
W. I. 4*	3461-3471	41	3461-3491	1400	1400		
	3477-3491	61					

*Injection Wells.

the lease interiors. Again referring to Fig. 1, the position of the injection wells, relative to the producing wells, is illustrated.

THE RESERVOIR

The reservoir being flooded in Langston-Kleiner field is comprised of three Strawn sand members which may have been separate sources of original accumulation, but which are now probably communicated by well completion practices. The middle sand member of the section is the best developed and most widespread of the three sands. An isopachous map of the net sand development in all three sand members is presented in Fig. 1. It will be noted that the sand lenses into shale to the west and southeast, that the northward extension of the sands are partially defined by water level of 2,380 ft subsea, and that the southern limit of the sand development is not entirely defined at the present time.

Core analyses are available from eight wells. The data obtained from these analyses indicate an average permeability of 47 md. and an average porosity of 15.2 per cent. Capillary pressure-fluid saturation measurements made on a selected group of core plugs indicated an average connate water for this Strawn section of 45.9 per cent of the pore space. Flushing tests per-

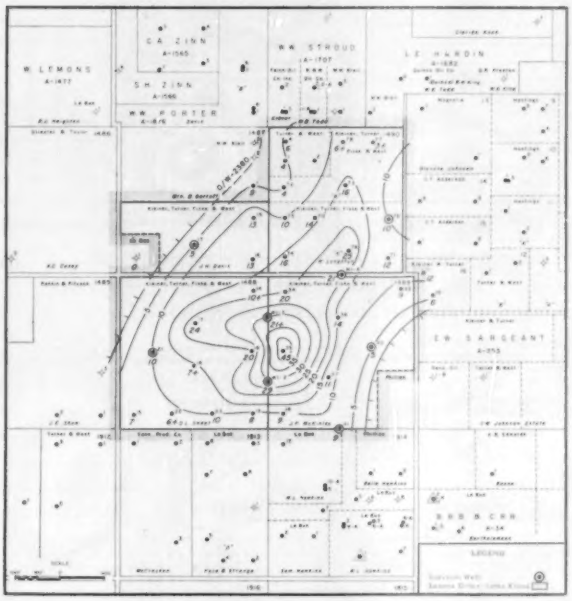

FIG. 1 — ISOPACHOUS MAP — NET OIL SAND OF 3,550 FT STRAWN RESERVOIR, LANGSTON-KLEINER FIELD, YOUNG COUNTY, TEX.

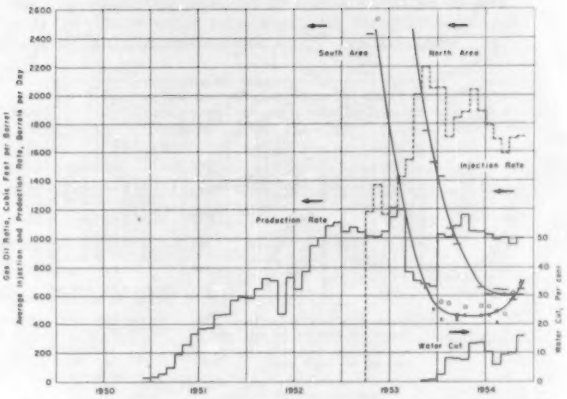

FIG. 2 — PRIMARY AND WATERFLOOD PRODUCTION HISTORY OF LEASES EFFECTED BY WATER FLOOD IN LANGSTON-KLEINER FIELD. DATA SUPPLIED THROUGH DEC. 1, 1954.

formed on restored state core plugs indicated an average residual oil saturation of 20.2 per cent of the pore volume and a relative permeability to water of 28.7 per cent at this residual oil saturation.

A reservoir fluid sample obtained early in the productive life of the field showed that the crude was saturated at the original reservoir pressure of approximately 1,600 psig. The saturated crude had a formation volume factor of 1.335 reservoir bbls/STB and a solution gas-oil ratio of 576 cu ft/bbl as measured by differential liberation. The viscosity of the reservoir crude at saturation pressure was 0.40 cp. At the average reservoir pressure of 787 psig existing at the start of the waterflood operation, the formation volume factor of the reservoir crude was 1.256 reservoir bbls/STB, the solution gas-oil ratio was 386 cu ft/bbl and the viscosity was 0.47 cp.

PRIMARY PRODUCTION HISTORY

The primary and waterflood production history of the Operators' leases, which are located in the waterflood area, is presented in Fig. 2. It will be noted that, following the inception of production in Dec., 1950, the monthly rate of oil production from these properties gradually increased to a peak of 37,211 bbls per month in Aug., 1953, with the completion of a total of 28 oil producing wells. By the time waterflood operations had commenced in April, 1953, the total cumulative production from the properties was 631,077 bbls of oil and the bottom-hole pressure had declined from an estimated original level of 1,600 psig to a measured level of 787 psig. The weighted average field gas-oil ratio had increased from the solution ratio of 576 cu ft/bbl to approximately 2,500 cu ft/bbl. No wells on the properties included in the waterflood area were producing water at the beginning of the injection.

Hydraulic fracturing of the producing section during the completion operations proved successful in increasing well productivity as early as mid-1952 and was generally considered routine in the completion of producing wells after that time. Many of the wells which had been completed prior to this date were subsequently subjected to hydraulic fracture treatment during workover operations. Later completions in the field have either been through perforations or a combination of open hole in the basal sand member and perforations in the upper members. Using a straddle packer, it became common practice to selectively fracture the individual zones. A summary of basic information on the fracture treatments is presented in Table 1 where it will be noted that the treatments employed ranged from 700 gal to 6,000 gal of fracture oil with a sand load of 1 lb/gal. These treatments averaged approximately 200 lbs of sand per foot of exposed section.

The effect of the fracture treatments on producing wells was to improve capacity to the extent that several pumping wells were restored to flowing status. The improvement in capacity has been sustained in most wells. It was also observed that temporary reduction in gas-oil ratio frequently occurred.

With only one exception, all injection wells were drilled specifically for the purpose of injection and were hydraulically fractured through perforations or in open hole in a manner similar to the treatments practiced

TABLE 2 — COMPARISON OF CALCULATED AND ACTUAL INJECTION RATES IN FRACTURED WELLS, LANGSTON-KLEINER FIELD, YOUNG COUNTY, TEX.

Injection Well No.	Capacity, Millidarcy Feet	Surface Pressure, Psig	Calculated Injection Rate, Bbls/Day	Actual Injection Rate, Bbls/Day*
W. I. No. 2	960	270	450	429
W. I. No. 3	665	760	454	407
Sweet No. 21	300	802	210	277

*Conditions as of Oct. 1, 1953.

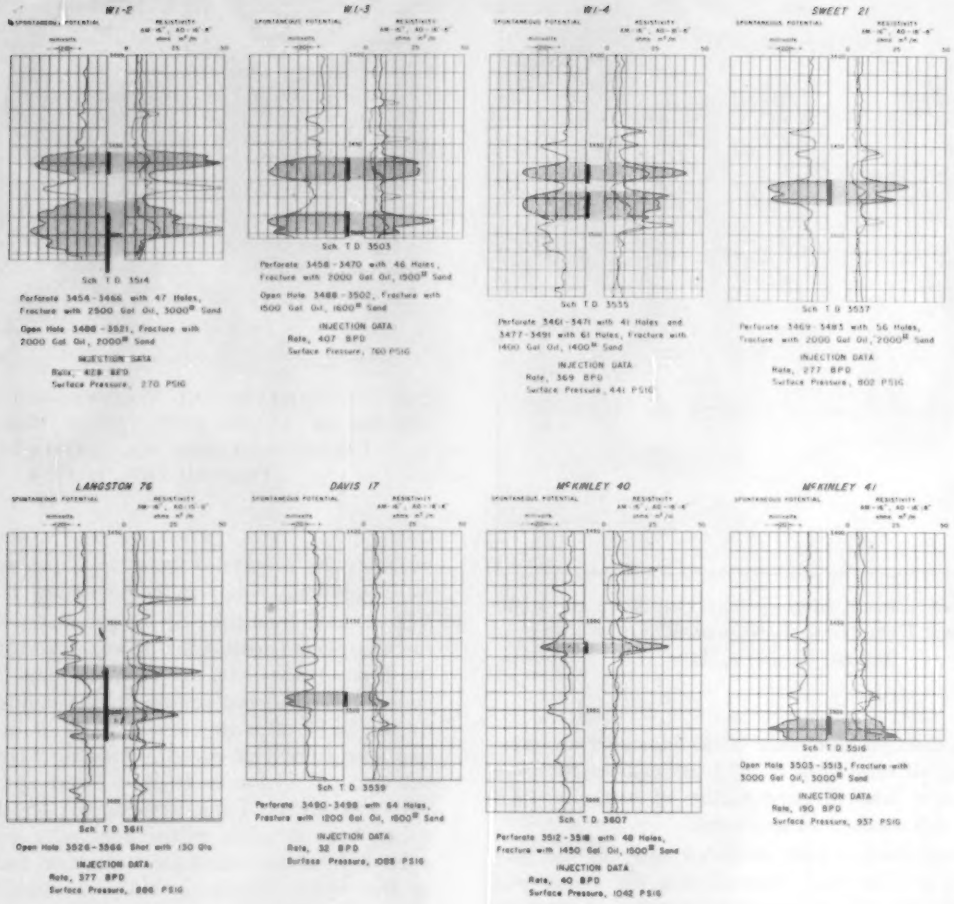
W I-2
Sch. T.D. 3514
Perforate 3454 - 3466 with 47 Holes, Fracture with 2500 Gal. Oil, 3000# Sand
Open Hole 3488 - 3521, Fracture with 2000 Gal. Oil, 2000# Sand
INJECTION DATA
Rate, 428 BPD
Surface Pressure, 270 PSIG
W I-3
Sch. T.D. 3503
Perforate 3458 - 3470 with 46 Holes, Fracture with 2000 Gal. Oil, 1500# Sand
Open Hole 3488 - 3502, Fracture with 1500 Gal. Oil, 1600# Sand
INJECTION DATA
Rate, 407 BPD
Surface Pressure, 760 PSIG
W I-4
Sch. T.D. 3555
Perforate 3461 - 3471 with 41 Holes and 3477 - 3491 with 61 Holes, Fracture with 1400 Gal. Oil, 1400# Sand
INJECTION DATA
Rate, 369 BPD
Surface Pressure, 441 PSIG
SWEET 21
Sch. T.D. 3537
Perforate 3469 - 3483 with 56 Holes, Fracture with 2000 Gal. Oil, 2000# Sand
INJECTION DATA
Rate, 277 BPD
Surface Pressure, 802 PSIG
LANGSTON 76
Sch. T.D. 3611
Open Hole 3526 - 3566 Shot with 130 Qts
INJECTION DATA
Rate, 377 BPD
Surface Pressure, 866 PSIG
DAVIS 17
Sch. T.D. 3539
Perforate 3490 - 3498 with 64 Holes, Fracture with 1200 Gal. Oil, 1600# Sand
INJECTION DATA
Rate, 32 BPD
Surface Pressure, 1088 PSIG
McKINLEY 40
Sch. T.D. 3607
Perforate 3512 - 3518 with 40 Holes, Fracture with 1450 Gal. Oil, 1500# Sand
INJECTION DATA
Rate, 40 BPD
Surface Pressure, 1042 PSIG
McKINLEY 41
Sch. T.D. 3516
Open Hole 3503 - 3513, Fracture with 3000 Gal. Oil, 3000# Sand
INJECTION DATA
Rate, 190 BPD
Surface Pressure, 957 PSIG

FIG. 3 — INJECTION WELL COMPLETION AND INJECTIVITY DATA, LANGSTON-KLEINER FIELD.

in the producing wells. The one injection well which has not been subjected to fracture treatment, the Langston No. 76, previously had been shot in open hole.

An attempt has been made to evaluate the effects of fracturing on injectivity by comparing the calculated injection capacity based upon core data to that actually experienced. The injection wells on which representative core data are available had sand sections of sufficient thickness and permeability to indicate substantial injection capacity prior to fracture treatment. It cannot be demonstrated that the relatively light fracture treatments applied to these better sand sections have had material effects on the injection capacity. This observation is borne out by reference to Table 2 wherein a comparison of calculated and actual injection rates is presented. Since injection conditions had become reasonably stable by Oct., 1953, but the reservoir had not yet responded in improved production characteristics, the average injection rates and pressures during this month were selected for comparison.

The injection wells which are located near the edge of the sand development, where the sand is thinner and less permeable, were not adequately cored. Therefore, specific analysis of the performance of these wells, the Davis No. 17, McKinley No. 40 and McKinley No. 41, is not possible. Inspection of the electric logs of these wells, shown in Fig. 3, serves to illustrate the tight broken character of the sections together with the injection volumes and surface pressures which have been experienced. In a qualitative sense, it is probably correct to conclude that the fracture treatments have been beneficial in increasing the ability of these tighter wells to accept the injected water at economic rates. The fact that all injection wells have satisfactorily received water, whether through perforations or in open hole, without extensive clean-out and swabbing operations demonstrates the economy of the fracture treatments over open hole shooting and cleaning out.

PERFORMANCE OF THE WATER FLOOD

Delays were encountered in equipping the field for water flooding which resulted in a more advanced stage of depletion existing in the reservoir at the inception of the program than had been anticipated in

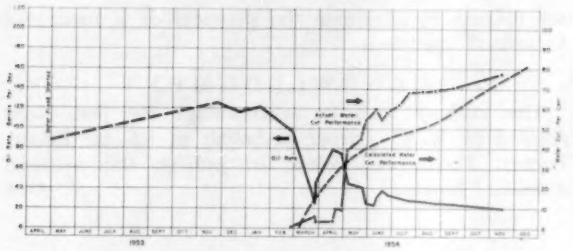

FIG. 4 — MCKINLEY NO. 35 WELL PRODUCTION HISTORY AFTER WATER FLOOD STARTED, LANGSTON-KLEINER FIELD.

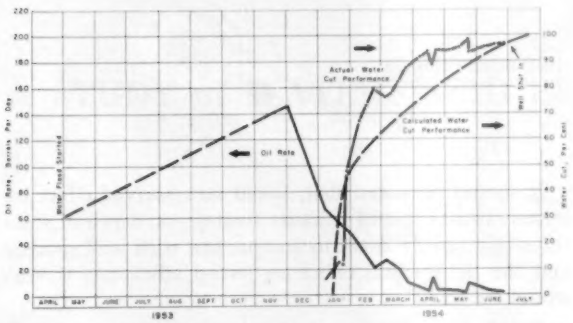

FIG. 5 — SWEET NO. 19 WELL PRODUCTION HISTORY AFTER WATER FLOOD STARTED, LANGSTON-KLEINER FIELD.

original planning. The reservoir pressure had declined to an average of 787 psig and increasing gas-oil ratios contributed to rates of voidage in excess of the rate of injection permissible with the existing wells. An arbitrary restriction in producing rate of the offending, high gas-oil ratio wells was effected in Sept., 1953, and continued through Dec., 1953.

The result of this temporary restriction is illustrated in Fig. 2. The gas-oil ratio immediately responded in each producing area under waterflood control and permanent reduction in rate of reservoir voidage was accomplished. This, in turn, has permitted gradual repressuring of the reservoir so that many of the producers have been restored to flowing status.

Only two wells had produced water to Aug. 1, 1954, as a result of the injection program. Water was first detected in individual well tests on the Sweet No. 19 well Jan., 1954, and on the McKinley No. 35 well in Feb., 1954. The source of water produced by these wells is thought to be from the McKinley-Sweet W. I. No. 2 injection well which is located 750 ft from each of the producers. The McKinley No. 35 well and McKinley-Sweet W. I. No. 2 injection well had been fractured and the Sweet No. 19 had not been fractured.

In analyzing the performance observed in these wells, it has first been necessary to estimate the flood pattern which existed around the W. I. No. 2 injection well at the time of breakthrough. Although potentiometric model work is not available on the project, reasonable accuracy is possible in approximating the pattern by resorting to a study of sand development and capacity in the surrounding wells. The general elongation of the pattern toward the McKinley No. 35 and Sweet No. 19 wells was suggested by this study and is confirmed by

TABLE 3 — VOLUMETRIC ANALYSIS OF DISPLACEMENT AS OF SEPT. 1, 1954. INJECTION WELLS FROM WHICH NO BREAKTHROUGH HAD OCCURRED, LANGSTON-KLEINER FIELD, YOUNG COUNTY, TEX.

Injection Well No.	Distance to Nearest Producing Well, Feet	Reservoir Vol. in Radial Pattern to Nearest Producing Well, Acre-Feet	Bbls Water Injected to 9-1-54	Bbls/AF Injected Into Radial Pattern
Davis No. 17	1,300	1,390	17,012	12
Langston No. 76	820	543	143,684	265
McKinley No. 40	970	442	20,964	47
McKinley No. 41	1,160	825	35,402	43
McKinley-Sweet W.I. 3	660	1,045	156,834	150
McKinley-Langston W.I. 4	510	467	162,143	347
Sweet No. 21	920	689	174,526	253

the lack of breakthrough in the McKinley No. 38 and Sweet No. 16 wells as of Aug. 1, 1954.

Based upon the estimated flood pattern, the residual saturation conditions previously stated and the permeability distribution found in the core analysis data on the region, theoretical calculations of water cut versus time relationships have been computed for the two wells in question. The computed performance is compared to the actual performance observed in well tests for McKinley No. 35 in Fig. 4 and for Sweet No. 19 in Fig. 5. The generally good agreement between computed and actual time of initial water appearance and subsequent rate of increase of water cut indicates that no abnormal by-passing or channeling has occurred.

Further confirmation of the lack of effects of the fracture treatments on the breakthrough performance is found in the analysis of the volumes of water which have been injected elsewhere in the field without creating breakthrough in the adjacent producing wells. Assuming a radial pattern of water advance from each injection well, a circle has been drawn passing through the nearest producing well. The reservoir volume thus enclosed has been determined and the amount of water which had been injected into this reservoir volume to Sept., 1954, has been computed in terms of barrels per acre-foot. These data are reported in Table 3. The injected volumes range upward to 347 bbl/acre-ft and generally indicate excellent performance of the flood advance in view of the lack of breakthrough in the nearest producing wells.

CONCLUSIONS

Based upon the 17 months experience in the Langston-Kleiner 3,550-ft sand waterflood operations, it is concluded that:

1. The degree of fracturing applied in this field has resulted in providing satisfactory injection rates through perforations and in open hole. It is probable that injection capacity has been increased in certain wells in which the sand development is poor. The necessity of shooting with nitroglycerine and the expense of clean-outs has thus been eliminated.

2. The breakthrough performance to date, accented by the lack of breakthrough over the major portion of the flood area, indicates that no detrimental effect on sweep efficiency is resulting from fracturing applied in this field.

3. The experience cited in this paper should not be interpreted as universal endorsement of fracture treatments in waterflood operations. Consideration of reservoir conditions and size of fracture treatments should be made and will undoubtedly have a bearing on the technique of flooding. However, as demonstrated here, past application of fracture treatments in a field does not necessarily eliminate the prospect of a successful waterflood operation.

ACKNOWLEDGMENT

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DISCUSSION

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Data presented by Roark and Lindner are believed to be the first in the literature relating actual field performance to the effect of fracture treatment on water flooding.

The conclusions reached by the authors are encouraging in view of the present extensive use of fracture treatment in primary production, but it should be emphasized that the limitations placed on those conclusions by the authors should not be overlooked. Quotation of the abstract of this paper in a recent paper on evaluation of flood prospects as a comment on "the unfavorable view expressed on large facture treatments" underlines the need of such emphasis since the fracture treatments used in the Langston-Kleiner field were not large.

It should be noted that, based on observed effect on injectivity and size of fracture treatments, depth of fractures is probably small in comparison with well spacing and the detrimental effect on sweep efficiency, if any, would be small.

Based on saturation and porosity values given, it appears that only one of the injection wells listed in Table 3 has received sufficient water to show conclusively lack of detrimental effect.

In view of the demonstrated benefits of fracturing on primary recovery it is hoped that the authors will review this paper at a later stage of depletion of the project and that others will present field data concerning this problem as it becomes available. ★★★

AUTHORS' REPLY to ROLAND GOULDY

Roland Gouldy observes that this paper has been quoted in a recent trade journal article with the inference that the authors have concluded that the experience in the Langston-Kleiner field may be expected to be reflective of waterflood performance of reservoirs which have been subjected to large fracture treatments. Judgment has specifically been reserved on the matter of the effect of size of treatments in all three conclusions stated at the close of the paper. The information presented and the conclusions drawn are restricted to conditions present in the subject field.

The further observation is made that only one well listed in Table 3 has received sufficient water to show conclusively lack of detrimental effect by fracturing. The total volume of mobile fluid to residual oil saturation in this reservoir is estimated to be 318 bbl/acre-ft. This volume should be reduced by the appropriate amount to account for areal coverage and stratification effects. Thus, the authors feel that data presented on Langston No. 76, McKinley-Langston W. I. 4 and Sweet No. 21 are significant in this respect. ★★★

A STUDY of WATERFLOOD EFFICIENCY in OIL-WET SYSTEMS

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ABSTRACT

A study of waterflood efficiency, given in terms of oil recovery at water breakthrough and ultimate recovery, has been made on short, consolidated Pyrex glass cores rendered oil-wet by chemical treatment. Contact angle, interfacial tension, permeability and porosity were the variables considered. Oil and water viscosities, core length and velocity of flooding were held constant.

The data permit interfacial tension, contact angle, porosity, and permeability to be grouped into a scaling coefficient along with viscosity, velocity of flooding and length of core. Correlation of the scaling coefficient with recovery at water breakthrough is found to follow prediction; correlations of ultimate recovery demand a scaling coefficient different from that which correlates breakthrough recovery.

The work indicates that, with proper control, a group of similar natural cores, of permeability plug size, can be correlated to indicate basic flooding performance.

INTRODUCTION

The fraction of oil recovered from a porous medium is related to both reservoir conditions and production techniques. An investigation of all factors that enter into this relationship is necessary in order to arrive at the optimum method of exploitation for oil reservoirs.

To define this relationship, laboratory studies have been made by a great many investigators. However, an important obstacle arises if the results of these experiments on water flooding are to be applied to practice. Differences in behavior are to be expected between reservoirs of the dimensions encountered underground and those used in laboratory work. Factors which play an important role under laboratory conditions may be of no consequence in reservoirs. Laboratory operating practices generally differ from field operating practices. Thus, a mere understanding of the mechanism of the displacement of oil by water is not enough. It is just as necessary that the process be analyzed dimensionally to give continuity and validity to the conversion from laboratory to field.

The theory of oil displacement that has come to be accepted by the majority of those who are associated with reservoir mechanics had its beginning in the work of Leverett[1] and Buckley and Leverett[2]. The banking of oil, observed by many previous workers, was described by the "fractional flow" and the "frontal advance" equations. The validity of the Buckley-Leverett theory was substantiated by the experimental and theoretical work of Terwilliger et al[3]; moroever, the theory was extended by the introduction of the idea of a "stabilized zone" to describe the banking of oil. Levine[5] showed that the Buckley-Leverett equations gave reasonable agreement between calculated and experimental breakthrough recoveries only if the capillary pressure and gravity terms were included.

Rapoport and Leas[4] investigated the properties of linear floods and showed that both breakthrough and maximum recovery are related to a "scaling coefficient" derived from the Buckley-Leverett equations. Jones-Parra and Calhoun[6] presented another scaling coefficient which included both viscous and capillary variables. Such scaling coefficients should suffice to predict waterflood efficiency. However, some experimenters report data which does not appear consistent with the scaling coefficient approach. For example, Engelberts and Klinkenberg[7] conducted an extensive series of experiments on a dimensional model which contained a

[1]References given at end of paper.

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TABLE 1 — SUMMARY OF CORE PROPERTIES

Core No.	L (cm)	Dia. (cm)	Pore Vol. (cm^3)	ϕ	ρ_g (gm/cm^3)
1.	3.72	2.11	4.80	.368	2.190
2.	3.72	2.03	4.30	.350	2.170
3.	3.74	2.07	4.04	.320	2.160
4.	3.72	2.07	4.78	.380	2.210
5.	3.68	2.03	3.92	.336	2.170
6.	3.76	2.07	4.60	.361	2.170
7.	3.71	2.10	4.70	.362	2.190
8.	3.70	2.02	3.90	.326	2.190
9.	3.66	2.04	3.88	.351	2.150
10.	3.74	2.08	4.59	.351	2.170
11.	3.70	2.04	4.39	.365	2.240
12.	3.73	2.05	4.05	.323	2.145
13.	3.70	2.07	4.95	.393	2.165
14.	3.71	2.04	5.00	.415	2.160
15.	3.69	2.10	4.70	.375	2.150
16.	3.73	2.01	4.45	.377	2.180
17.	3.69	2.01	3.98	.333	2.150
18.	3.74	2.07	4.69	.374	2.200
19.	3.71	2.09	5.02	.394	2.170
20.	3.71	2.02	4.50	.373	2.180
21.	3.71	2.01	4.40	.362	2.190
22.	3.73	2.10	5.03	.399	2.180
23.	3.71	2.09	4.68	.375	2.190
24.	3.70	2.05	4.53	.361	2.200
25.	3.71	2.05	4.53	.361	2.200
26.	3.74	2.04	4.34	.352	2.190
27.	3.73	2.10	4.43	.356	2.215
28.	3.78	2.05	4.04	.321	2.215
29.	3.69	2.05	4.50	.362	2.160
30.	3.73	2.05	4.40	.355	2.190
31.	3.74	2.08	4.50	.351	2.200
32.	3.70	2.04	4.11	.357	2.250
33.	3.71	2.04	4.60	.358	2.200
34.	3.74	2.04	4.45	.356	2.190
35.	3.69	2.05	4.29	.349	2.180
36.	3.74	2.14	5.15	.391	2.190
37.	3.72	2.09	4.39	.337	2.160
38.	3.72	2.10	4.26	.360	2.190

TABLE 1 — SUMMARY OF CORE PROPERTIES
(Continued)

Core No.	K (Darcy)	$\sqrt{K\phi}$	$\sqrt{\frac{K}{\phi}}$
1.	.860	.563	1.529
2.	.860	.550	1.568
3.	.507	.403	1.260
4.	.898	.593	1.540
5.	1.280	.655	1.950
6.	.985	.598	1.652
7.	.820	.545	1.505
8.	.570	.431	1.322
9.	1.302	.676	1.930
10.	.950	.580	1.605
11.	.892	.571	1.563
12.	.602	.440	1.368
13.	1.122	.665	1.690
14.	1.580	.810	1.952
15.	1.060	.635	1.690
16.	1.070	.635	1.445
17.	.657	.468	1.420
18.	.770	.540	1.445
19.	1.570	.780	1.995
20.	1.190	.665	1.787
21.	1.100	.630	1.743
22.	1.270	.710	1.775
23.	.668	.500	1.333
24.	.870	.560	1.551
25.	.765	.535	1.430
26.	.685	.486	1.380
27.	.530	.434	1.220
28.	.520	.445	1.275
29.	.740	.477	1.428
30.	.855	.550	1.550
31.	.593	.456	1.300
32.	.770	.525	1.472
33.	.670	.490	1.368
34.	.888	.563	1.576
35.	.968	.581	1.662
36.	1.060	.645	1.650
37.	.710	.490	1.450
38.	1.515	.739	2.050

total of 12 independent variables; they concluded that water-wet systems had an anamolous behavior at high viscosity ratios. Jones-Parra, Stahl, and Calhoun[8] reported experimental results in which they show agreement with the Buckley-Leverett theory only on the basis of the time dependency of both the saturation gradient and the fractional flow equation. Warren and Calhoun[12] have extended this to indicate the test conditions under which a stabilized flood has occurred.

The immediate problem is to introduce sufficient control into experimentation so that the variables appearing in the scaling coefficient can be separated and their individual roles evaluated. This experimental work was begun with that thought in mind. Since the breakthrough recovery appears specifically in correlations based on theory, it was taken to be a standard for comparison. In addition, it was deemed desirable to compare efficiency at some common endpoint. Therefore, ultimate recovery, as used here, is defined as the oil recovered after injection of 20 pore volumes of brine.

EXPERIMENTAL PROCEDURE

Material and Equipment

The cores used in the experimental work were fritted, "Pyrex" brand, chemical glass. They were designated as medium porosity and had a nominal pore diameter of 10 to 15 microns. The cores were cleaned by washing with hot hydrochloric acid to insure that they were completely water wet. The ends were then cut off to eliminate any inhomogeneities due to the manufacturing process; this gave a core length of 3.71± .05 cm. The diameter as manufactured was 2.05± .05 cm. Air permeabilities and porosities (using distilled water to avoid contamination) were determined for all cores. A summary of core properties is given in Table 1.

The displacing phase was .25N brine solution with 10 parts of $HgCl_2$ per million parts of brine added to prevent bacterial growth. The properties of the brine are

$\overline{L}$ = 3.71 cm

$\overline{d}$ = 2.06 cm

ρ_g = 2.192 gm/cm³

ρ_{pyrex} = 2.230 gm/cm³ (Corning Glass Co.)

listed in Table 2. This displacing fluid will be called simply "brine" in the remainder of this discussion.

The displaced liquids were mixtures of organic liquids which were immiscible with brine and were not solvents for Dri-film. The mixtures were chosen so that they would have equal viscosities but different interfacial tensions against brine. These test fluids, referred to as I, II, III and IV, had viscosities of 1.94± .04 cp and a spread in interfacial tension from 12.9 to 61.2 dynes/cm. The fluid properties and compositions are given in Table 2. Since it was realized that the displaced fluids would be in contact with the neoprene sleeve of the test apparatus, a piece of neoprene was allowed to soak in each of the organic liquids for 24 hours. This resulted in a lowering in the interfacial tensions of from .6 to 5.8 dynes/cm. These interfacial tension values are also recorded in Table 2 and are the values used for correlations.

The test set-up, shown in Fig. 1, was designed and constructed to: (1) permit quick and simple mounting and dismounting of the cores and prevent leakage of fluid, (2) allow measurement of the displacement pressure of the core after it was mounted for the run, (3) furnish a means for flooding the cores with brine at a constant rate, and (4) provide a method for the accurate measurement of breakthrough recovery without dismounting the core.

It was felt that these objectives were satisfactorily attained by: (1) using the Hassler sleeve type of core mount, (2) using a constant rate displacement pump (Milton Roy Mini-pump) with a surge filter, and (3) employing electrical conductivity to determine time of

PROCEDURE

breakthrough. Brass, Saran, Pyrex glass, Tygon and Neoprene were used in the construction of the equipment.

It was decided that three variables would be studied; they were γ, $\sqrt{K\phi}$ and cos Θ. By holding L, v, c and μ_w constant, the independent effects of the indicated variables could be investigated by making 28 runs. The runs were set up on this basis:

	$\sqrt{K\phi_1}$	$\sqrt{K\phi_2}$	$\sqrt{K\phi_3}$	$\sqrt{K\phi_4}$
γ_1	$\cos\Theta_1$	$\cos\Theta_1$	$\cos\Theta_1$	$\cos\Theta_1$
	$\cos\Theta_2$	$\cos\Theta_2$	$\cos\Theta_2$	$\cos\Theta_2$
	$\cos\Theta_3$	$\cos\Theta_3$	$\cos\Theta_3$	$\cos\Theta_3$
	$\cos\Theta_4$	$\cos\Theta_4$	$\cos\Theta_4$	$\cos\Theta_4$
γ_2	$\cos\Theta_1$	$\cos\Theta_1$	$\cos\Theta_1$	$\cos\Theta_1$
γ_3	$\cos\Theta_1$	$\cos\Theta_1$	$\cos\Theta_1$	$\cos\Theta_1$
γ_4	$\cos\Theta_1$	$\cos\Theta_1$	$\cos\Theta_1$	$\cos\Theta_1$

The variations in $\sqrt{K\phi}$ were inherent in the cores themselves; γ was varied by using the four organic liquid mixtures described in Table 1; it was decided to vary cos Θ by treatment with Dri-film as suggested by Bethel[9]. A group of capillary tubes was treated and tested to determine the effect of concentration on the

TABLE 2 — FLUID PROPERTIES AND COMPOSITIONS

Fluid	Composition	ρ (gm/cm³)	μ (cp)	γ_1 (dynes/cm)	γ_2 (dynes/cm)
Brine	.25 N Na Cl 10 parts/10⁶ Hg Cl_2	1.010	.935	----	----
I	82.1% (Vol.) n-dodecane 17.9% (Vol.) Mineral Oil	.770	1.98	61.2	55.4
II	62.1% (Vol.) CCl_4 37.9% (Vol.) octanol	1.294	1.96	13.3	12.9
III	77.5% (Vol.) n-dodecane 22.5% (Vol.) octanol	.762	1.91	26.0	20.2
IV	36.5% (Vol.) octanol 27.6% (Vol.) n-dodecane 32.9% (Vol.) CCl_4 3.0% (Vol.) Mineral Oil	1.140	1.97	12.9	11.8

$\overline{\mu_o} = 1.954$ cp $\dfrac{\overline{\mu_o}}{\mu_w} = c = 2.09$

γ_1 = original oil-brine interfacial tension.

γ_2 = interfacial tension after soaking neoprene in oil for 24 hours.
Temperature = 22.0 – 23.5°C.

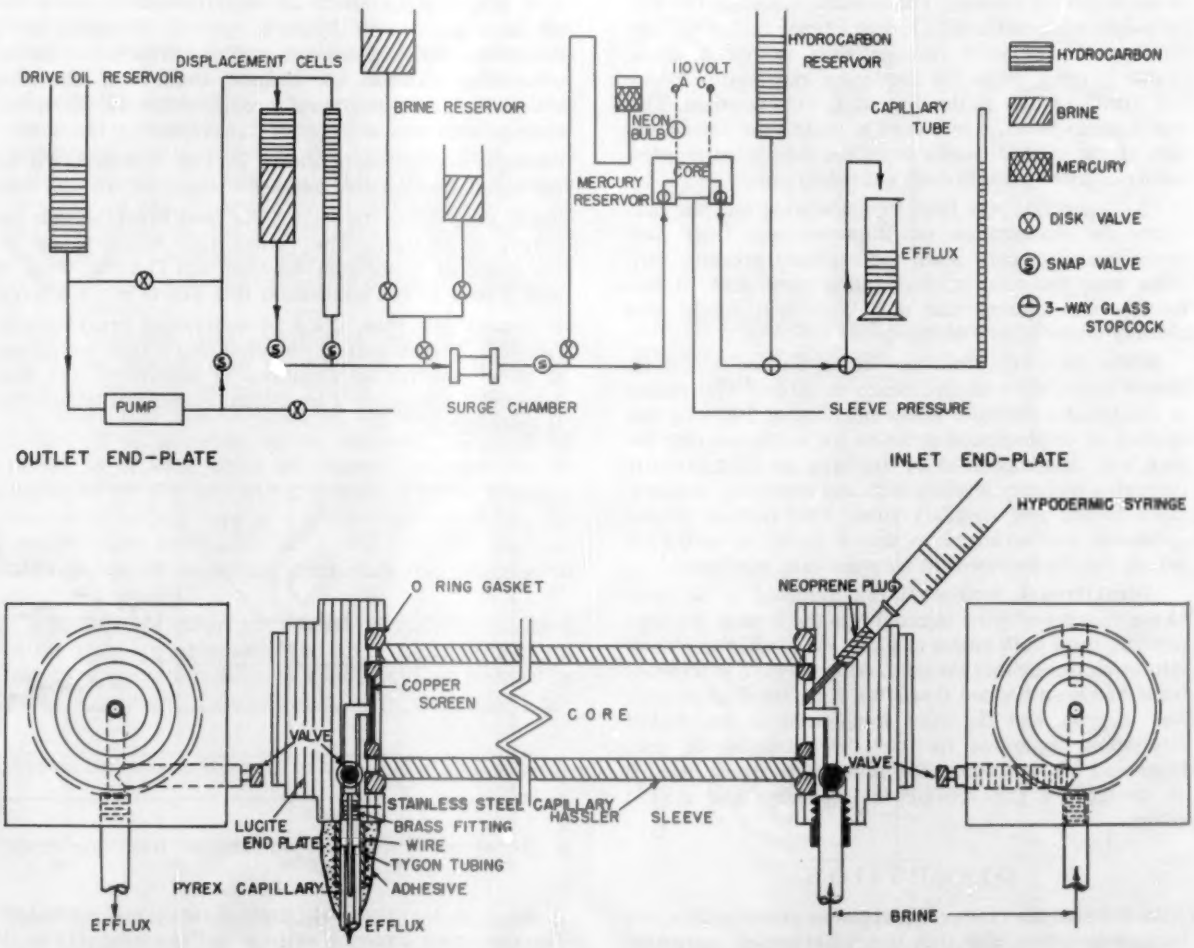

FIG. 1 — EXPERIMENTAL APPARATUS.

TABLE 3 — CAPILLARY PRESSURE DATA FOR WATER WET CORES
(CORES CLEANED WITH HCl — UNTREATED WITH DRI-FILM)

	P_c (cm Hg)	Q_T (cm^3)	S_w (%)	$\lim_{S_w \to} i(S_w)$ 1.0	k
Core No. 24	7.1	0	100.0	.202	24.5
	8.0	.55	88.0		
	9.6	1.27	71.4		
	11.8	2.26	50.9		
	14.2	3.16	31.3		
	19.3	3.80	17.6		
	25.4	4.07	11.6		
	34.6	4.21	8.5		
	39.0	4.23	8.2		
Core No. 36	7.0	0	100.0	.212	22.2
	7.4	.37	92.8		
	8.8	1.65	68.0		
	12.0	3.13	39.2		
	15.2	3.92	24.0		
	18.7	4.41	14.4		
	29.4	4.74	8.0		
	40.5	4.82	6.4		
Core No. 3	7.2	0	100.0	.166	36.4
	9.6	.58	85.6		
	12.4	1.36	66.4		
	16.0	2.58	36.0		
	19.9	3.08	23.9		
	24.6	3.51	13.2		
	39.1	3.64	9.9		
Core No. 15	7.0	0	100.0	.218	21.0
	7.1	.41	91.2		
	8.3	1.31	72.1		
	11.7	3.00	36.1		
	18.2	3.98	15.2		
	28.6	4.25	9.6		
	42.9	4.34	7.6		

contact angle. These tests indicated that reasonable control could be exercised over the contact angle. On the basis of these tests, 33 cores were treated with Dri-film in solution with toluene. The concentrations of Dri-film by weight were .001, .01, .1, and 1.0 per cent. Capillary pressure curves were run on four untreated cores, (Table 3) using air as the displacing, non-wetting phase and distilled water as the displaced, wetting phase. This was done to obtain a reference to permit the determination of the contact angles from the displacement pressures measured prior to each individual run.

The pump rate was fixed by calculating the rate necessary for stabilization on Rapoport and Leas' Dri-filmed alundum core when the capillary pressure variables were included in the scaling coefficient. It was found that a pump rate of 5.0 cc/min would give a safety factor of two on this basis.

Before each run, the core to be flooded was completely saturated with hydrocarbon. After being placed in the Hassler sleeve, a sleeve pressure of 100 psig was applied. A displacement pressure for water entering the core was then measured by applying an inlet pressure through a mercury leveling bulb and observing displacement in the fine capillary tube. This portion of the apparatus was arranged so that it could be sealed off before the displacement at constant rate was begun.

Breakthrough recovery was considered to be equal to the volume of brine injected into the core at the time that the neon bulb began to glow, thus indicating water saturation throughout the core. After 20 pore volumes of brine had been flooded through a core, the displacement was stopped and the core transferred to an ASTM distillation apparatus for the determination of final brine and oil saturation. The ultimate recovery listed is an average of the volumetric (recovery) and ASTM values.

DISCUSSION

In the analysis of the displacement pressure data, the basic assumption was that the acid-cleaned, untreated cores were water-wet (cos $\Theta = 1.0$). The values of the Kozeny constant were calculated from capillary pressure data in Table 3 as suggested by Rose and Bruce[10] and plotted in Fig. 2. The linearity of this plot implies that the hydraulic radius, r, was constant for these cores. Since Carman[11] has shown that the average pore diameter, $\overline{d}$, is equal to twice the hydraulic radius, it was possible to determine $\overline{d}$. Its value was found to be 23.2×10^{-4} cm; this agrees fairly well with the manufacturer's value of $10 - 15 \times 10^{-4}$ cm for this type core.

The value of cos Θ was determined for each run by taking the value of the Kozeny constant from the graph in Fig. 2 and substituting it in the following equation:

$$\cos\Theta = \frac{P_D}{\gamma\sqrt{\frac{1}{k}}}\sqrt{\frac{K}{\phi}}$$

where $\sqrt{\frac{1}{k}}$ is the limiting value of the j-function as 100 per cent wetting phase saturation is approached.

A plot of the experimentally determined values of cos Θ is shown in Fig. 3. Averaging the values at each concentration gives a linear plot vs log of the concentration.

A graphical summary of breakthrough recovery for all runs made with Fluid I ($\gamma = 55.4$ dynes/cm), except run 15, is presented in Fig. 4 with cos Θ as the correlating variable. A definite trend was observed which indicates that breakthrough recovery varies inversely with cos Θ. Fig. 5 is a replot of the breakthrough recovery data shown in Fig. 4 with $\sqrt{K\phi}$ as the correlating variable and cos Θ constant. An excellent linear correlation between $\sqrt{K\phi}$ and breakthrough recovery is obtained. The variation in recovery was of the order of 6 per cent for each cos Θ value. Figs. 4 and 5 lead to the conclusion that cos Θ plays a more important role than $\sqrt{K\phi}$ in controlling breakthrough recovery. It may also be observed that a tight formation is more sensitive to variations in wettability and that recovery approaches a maximum as neutral wettability is approached.

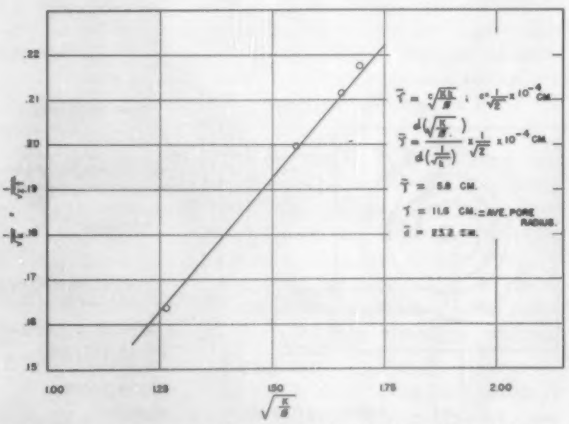

FIG. 2 — VALUES OF THE KOZENY CONSTANT CALCULATED FROM CAPILLARY PRESSURE DATA IN TABLE 3 AS SUGGESTED BY ROSE AND BRUCE[10].

In Fig. 6, the data from the preceding runs using Fluid I and the remainder of the data using Fluids II, and III and IV are plotted against γ with $\sqrt{K\phi}$ and cos Θ held constant. These curves indicate a linear decrease in recovery as γ is increased; the decrease is substantial. It is inferred that γ, as well as cos Θ is more important than $\sqrt{K\phi}$ in controlling breakthrough recovery. This inclusion of γ in the scaling factor follows the experimental data published by Root[12].

Fig. 7 offers a plot of all the data with breakthrough recovery vs the generalized, dimensionless scaling coefficient inferred from the theoretical work of Jones-Parra and Calhoun[6]. For this plot average values of cos Θ as read from Fig. 3 are used. This representation shows a linear trend within each $\sqrt{K\phi}$ group. This would be expected since it is actually a plot of the equation for breakthrough recovery

$$\text{Recovery} = A - B\frac{\gamma \cos \Theta \sqrt{K\phi}}{cLv\mu w}\Psi$$

where A and B are constants only if (1) a constant $j(S_w)$ correlation and (2) the same relative permeability curves apply to all cores under consideration. This makes it impossible to correlate the breakthrough recovery in Fig. 7 on a single plot for all cores. The failure to correlate lies in the inability to include all factors in the recovery equation. In particular, the absolute permeability or the cos Θ might not be properly included. In this group of cores, the pore size distribution was shown to be uniform; therefore, changes in absolute permeability must have been due to different tortuosities. Changes in cos Θ will limit the validity of the $j(S_w)$ function at low wetting phase saturations and thus change the degree to which cos Θ enters the recovery equation. This can be seen more explicitly in Fig. 5. At the two higher values of cos Θ, the first power of cos Θ will serve to bring the data into a single correlation, but at the two lower values of cos Θ, approximately the square of cos Θ is necessary to correlate.

The tabulated data and Fig. 4 show the effect of cos Θ on the ultimate recovery; as cos Θ increases, ultimate recovery increases. This is exactly opposite to the effect that cos Θ produced on breakthrough recovery. It is, however, in the direction suggested by Bethel, et al[9]. The effect on ultimate recovery can be explained by the fact that the wetting phase covers a maximum surface area at a given saturation when the contact angle approaches zero; this prolongs the funicular region of saturation, permitting the achievement of a lower residual.

The different values of residual oil can be considered in the recovery equation if the $j(S_w)$ function is modified to account for different residuals. This is done by using a reduced function $j(S_w')$ vs a reduced saturation S_w' which is equal to $\frac{S_w - S_{or}}{1 - S_{or}}$. The scaling coefficient then becomes $\frac{\gamma \cos \Theta \sqrt{K\phi}}{cLv\mu_w(1 - S_{or})}$. In Fig. 8, breakthrough recoveries plotted vs this coefficient indicate a reasonable linearity for each Dri-film treatment (approximately constant cos Θ).

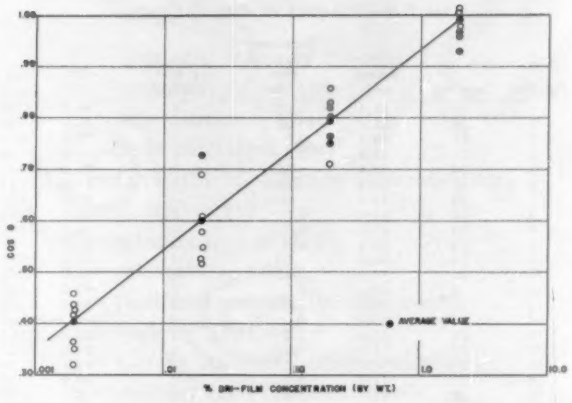

FIG. 3 — A PLOT OF THE EXPERIMENTALLY DETERMINED VALUES OF COS Θ.

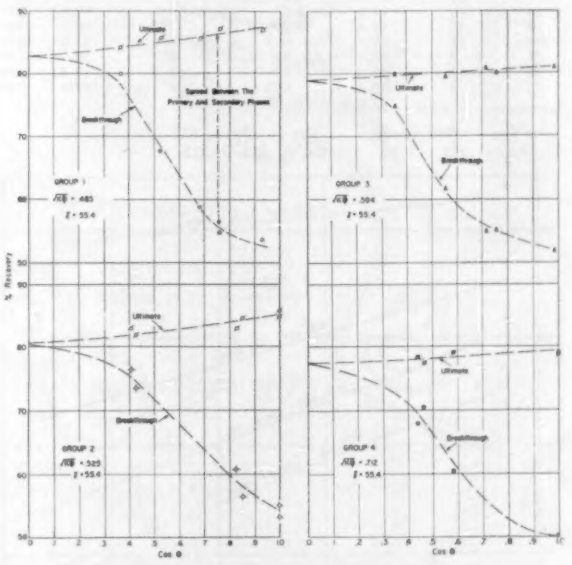

FIG. 4 — GRAPHICAL SUMMARY OF BREAKTHROUGH RECOVERY FOR ALL RUNS MADE WITH FLUID I ($\gamma = 55.4$ DYNES/CM) EXCEPT RUN 15. COS Θ IS THE CORRELATING VARIABLE.

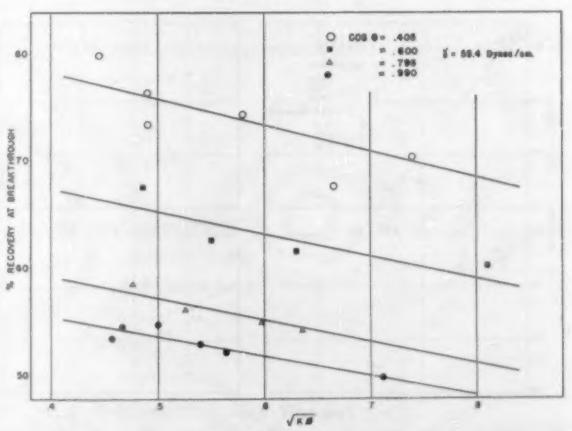

FIG. 5 — REPLOT OF THE BREAKTHROUGH RECOVERY DATA SHOWN IN FIG. 4 WITH $\sqrt{K\phi}$ AS THE CORRELATING VARIABLE AND COS Θ CONSTANT.

TABLE 4 — SUMMARY OF RECOVERY DATA

Run No.	Core No.	γ (dynes/cm)	Treatment (% Dri-Film by wt)	$\sqrt{K\phi}$* Group	Q_T (cm³)	Time (sec)
1	28	55.4	.002	1	80.8	1029
2	26	55.4	.02	1	86.7	1108
3	17	55.4	0.2	1	79.6	1071
4	31	55.4	2.0	1	90.0	1148
5	33	55.4	.002	2	91.6	1180
6	10	55.4	.002	3	91.4	1181
7	38	55.4	.002	4	85.0	1074
8	16	55.4	0.2	3	88.9	1086
9	32	55.4	0.2	2	82.2	1053
10	23	55.4	2.0	2	93.7	1197
11	14	55.4	.02	4	100.0	1275
12	21	55.4	.02	3	88.0	1176
13	6	55.4	0.2	3	92.0	1187
14	34	55.4	2.0	3	88.9	1187
15	19	55.4	0.2	4	Core Fractured	
16	22	55.4	2.0	4	100.6	1308
17	27	12.9	.002	1	88.6	1025
18	25	12.9	.02	2	93.1	1184
19	11	12.9	0.2	3	87.8	1196
20	20	12.9	2.0	4	90.0	1160
21	12	20.2	.002	1	80.1	1026
22	30	20.2	.02	2	88.0	1080
23	4	20.2	0.2	3	95.6	1215
24	9	20.2	2.0	4	77.6	990
25	8	11.8	.002	1	76.0	995
26	7	11.8	.02	2	93.9	1198
27	35	11.8	0.2	3	92.0	1072
28	13	11.8	2.0	4	99.8	1284
29	29	55.4	0.20	1	90.0	1097
30	37	55.4	.002	2	85.8	1095
31	2	55.4	.02	2	86.0	1192
32	18	55.4	2.0	2	93.8	1188
33	5	55.4	.002	4	78.4	960

Temperature = 22.0 — 24.8°C

* $\sqrt{K\phi_1}$ = .400 — .486 $\sqrt{K\phi_3}$ = .556 — .635
$\sqrt{K\phi_2}$ = .487 — .555 $\sqrt{K\phi_4}$ = .636 — .810

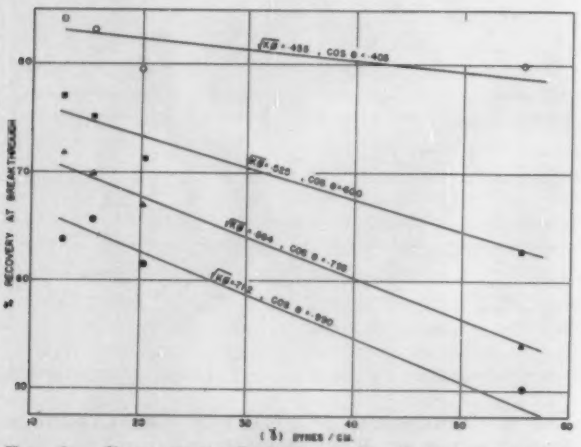

FIG. 6 — DATA FROM PRECEDING RUNS USING FLUID I AND REMAINDER OF DATA USING FLUIDS II, III, AND IV ARE PLOTTED AGAINST γ WITH $\sqrt{K\phi}$ AND COS θ HELD CONSTANT.

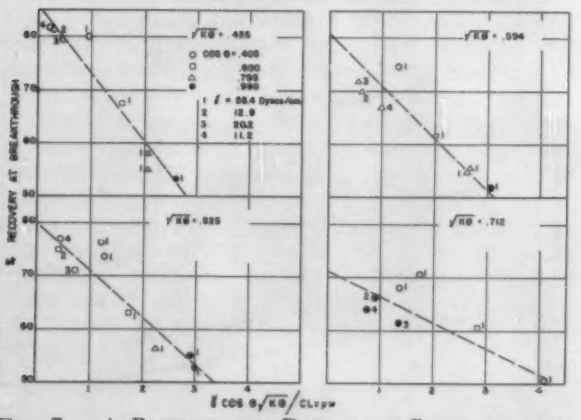

FIG. 7 — A PLOT OF ALL DATA WITH BREAKTHROUGH RECOVERY VS THE DIMENSIONLESS SCALING COEFFICIENT INFERRED FROM THE THEORETICAL WORK OF JONES-PARRA AND CALHOUN[6].

TABLE 4 — SUMMARY OF RECOVERY DATA (Continued)

Run No.	P_D (cm Hg)	cos θ	Breakthrough Recovery (% Pore Vol.)	Ultimate** Recovery (% Pore Vol.)	$\frac{\gamma \cos\theta \sqrt{K\phi}}{c l v \mu_w}$ (dimensionless)	$\frac{\gamma}{\cos\theta}\sqrt{\frac{\phi}{K}}$
1	2.1	.364	80.0	84.2	.96	107.3
2	2.8	.525	67.8	85.5	1.55	40.7
3	3.6	.760	54.8	87.0	2.05	49.1
4	4.7	.930	53.6	86.8	2.61	43.1
5	2.5	.430	73.7	82.0	1.13	100.0
6	1.5	.350	74.7	79.8	1.28	86.8
7	1.5	.462	70.5	77.5	1.69	66.9
8	2.8	.710	54.9	80.8	2.60	48.0
9	3.0	.856	56.4	84.8	2.25	47.4
10	4.0	1.010	55.0	84.9	2.89	42.0
11	2.1	.580	60.5	79.1	2.70	47.4
12	2.0	.550	61.8	79.4	2.02	53.1
13	2.7	.750	55.1	80.1	2.64	42.2
14	3.5	.980	52.0	80.9	3.12	35.5
15	— Core Fractured —					
16	3.2	1.005	50.0	79.0	4.15	31.5
17	.6	.430	83.0	86.5	.23	26.1
18	1.4	1.320	75.0	84.3	.40	15.1
19	2.8	.800	70.0	81.5	.59	10.4
20	1.0	.961	66.0	82.2	.86	53.1
21	.5	.270	79.5	85.6	.38	36.5
22	.8	.518	71.2	85.3	.70	21.8
23	1.1	.720	66.9	82.0	.99	16.5
24	1.5	.965	61.4	81.5	1.37	11.6
25	1.0	.320	84.1	86.8	.20	22.0
26	.3	.690	77.0	86.4	.41	13.1
27	.6	.820	71.8	82.5	.55	9.0
28	.7	.980	63.7	83.0	.78	7.1
29	3.4	.680	58.8	85.5	.20	48.9
30	2.0	.410	76.6	83.1	1.20	94.4
31	2.3	.830	62.8	83.1	1.73	59.0
32	4.4	1.060	53.2	86.1	2.97	38.4
33	1.6	.435	67.8	78.5	1.43	70.2

**average of gravimetric and volumetric values

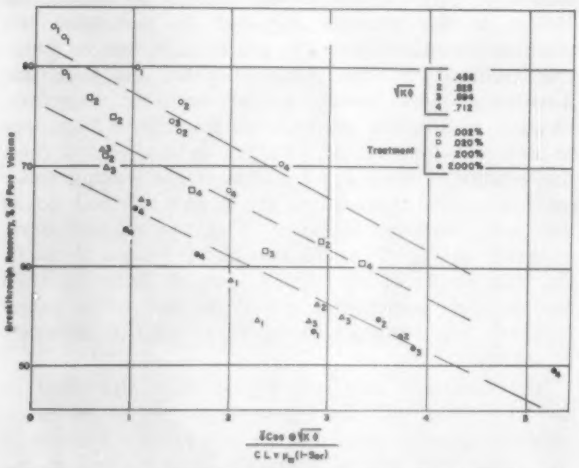

FIG. 8 — BREAKTHROUGH RECOVERIES PLOTTED VS SCALING COEFFICIENT.

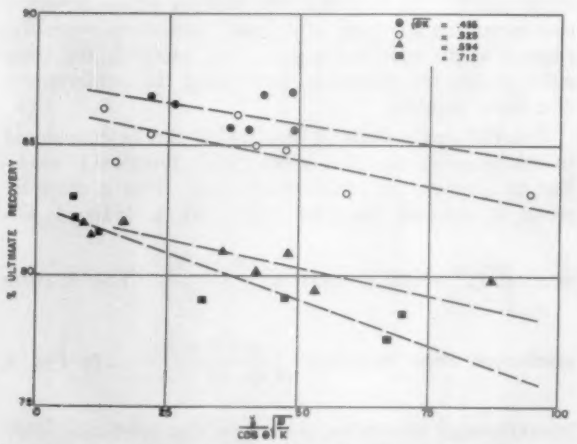

FIG. 9 — ULTIMATE RECOVERY DATA VS GENERALIZED CORRELATION FUNCTION.

The data also indicate a decrease in ultimate recovery with an increase in γ while all other factors are held constant. The most reasonable explanation of the observed results is that as γ increases, the radius of curvature of the wetting phase increases for a given pressure. This indicates that the volume of fluid trapped at the maximum applied pressure would increase as γ and the radius of curvature increases, with wettability held constant.

Fig. 9 is a plot of all the ultimate recovery data against a generalized correlation function. This shows that although the same variables control ultimate recovery as control breakthrough recovery the variables must be combined in a different manner.

ERRORS

It is impossible to evaluate the possible or even probable errors in an experiment of this type. However, it is possible to compare the results from four pairs of cores having similar wettability and $\sqrt{K\phi}$ values and saturated with the same fluid. For breakthrough recovery, the variation was 1.9 per cent of pore volume from the mean value; for ultimate recovery, the variation was $\pm$ .6 per cent of pore volume from the mean value. In Fig. 4 the duplicate run data are plotted to show the magnitude of the differences.

CONCLUSIONS

The following conclusions were drawn from these tests:

1. Fritted Pyrex cores can be treated to reasonably well-controlled degrees of wettability; the cores have uniform pore size distribution but varying tortuosity.

2. The cos Θ calculated from displacement pressures is a reasonably good quantitative measure of wettability.

3. Breakthrough recovery correlates with $\gamma \cos \Theta \sqrt{K\phi}$.

4. Ultimate recovery at 20 pore volumes of throughput correlates with

$$\frac{\gamma}{\cos \Theta} \sqrt{\frac{\phi}{K}}.$$

5. The equation for breakthrough recovery presented by Jones-Parra and Calhoun was validated for the group of cores studied; however, it was recognized that it was limited in its range of applicability by the effect of tortuosity on the relative permeability function and the effect of wettability on the $j(S_w)$ function.

ACKNOWLEDGMENT

The data in this paper are extracted from a thesis by J. E. Warren which was submitted to The Pennsylvania State University in partial fulfillment of requirements for the M S degree. Warren held the Stanolind fellowship in petroleum engineering at The Pennsylvania State University during the majority of the time while this research was in progress. A part of the laboratory equipment, materials, and general assistance was given Warren by the South Penn Oil Co. research project at the University.

NOMENCLATURE

γ = interfacial tension (dynes/cm)
Θ = contact angle (degrees)
d = pore diameter (cm)
r = hydraulic radius (cm)
$j(S_w)$ = Leverett's "j" function (dimensionless)
S = saturation (%)
P = pressure (cm of Hg)
K = permeability (darcy)
ϕ = fractional porosity (dimensionless)
μ = viscosity (cp)
k = Kozeny constant (dimensionless)
c = viscosity ratio (dimensionless)
L = length (cm)
v = velocity (cm/min)

$$\Psi(Sw_D) = \int_{Sw_i}^{Sw_D} \left[\frac{FwKo \dfrac{\partial j(Sw)}{\partial Sw}}{Fw - f_w} \right] d\,Sw$$

Q = volume (cm^3)

q = flow rate $\left(\dfrac{cm^3}{min}\right)$

ρ = density (gm/cm^3)

$$F_w = \frac{1}{1 + \dfrac{K_o}{K_w}\dfrac{\mu_w}{\mu_o}}$$

$$f_w = \frac{1 - \dfrac{KoA}{q_t \mu_o}\left(\dfrac{\partial Pc}{\partial Sw}\dfrac{\partial Sw}{\partial u}\right)}{1 + \dfrac{Ko}{Kw}\dfrac{\mu_w}{\mu_o}}$$

t = tortuosity (dimensionless)

Subscripts

w = water
o = oil
D = displacement
V = variable zone
S = stabilized zone
i = initial
T = total
C = capillary
g = grain

Superscript

$-$ = average

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WELL PRODUCTIVITY INCREASE from DRAIN HOLES as MEASURED by MODEL STUDIES

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ABSTRACT

The use of drain holes drilled from a well to improve productivity is becoming increasingly common. This paper presents data on the productivity increase that may be expected. The data were obtained by use of an electrolytic tank model of a reservoir. Parameters varied in the study to show their effect on productivity include the length, number, and arrangement of drain holes, formation thickness, and damage near the wellbore.

The most important results are that very large increases in productivity can be expected only in damaged wells. The distance to which drain holes penetrate is of primary importance. Additional length is more effective than increasing the number of drain holes.

INTRODUCTION

In planning the use of drain holes to improve productivity, it is important to be able to estimate the increase in production that can be obtained for a given expenditure. It is also important to know what combination of parameters related to the use of drain holes can be chosen to give the largest production increase. This paper presents data on the productivity increase that may be expected, as obtained by use of an electrolytic tank model of the reservoir. In this study, a number of parameters were varied to show their effect on productivity. These included the length, number, and arrangement of the drain holes. The presence or absence of a damaged zone of low permeability around the wellbore and the thickness of the producing formation were also considered.

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DEFINITIONS AND ASSUMPTIONS

The productivity increase that might be expected due to drain holes is presented as the ratio: productivity of a well after drain holes are drilled and completed to the productivity of the same well in an undamaged state without drain holes. The symbol Q/Q_o is used to represent this productivity ratio. Thus, the comparison in each case is with a formation of uniform and undamaged permeability.

Additional notation includes r_b for the radial extent of the damaged zone, which is assumed to be cylindrical and concentric with the wellbore. Thus the effect of an actual block is approximated by a discontinuous variation in permeability. For purposes of this paper, the permeability within the damaged zone, denoted by k_b, is assumed to be 1/25 that in the remainder of the formation, or k.

A necessary assumption in making comparative tests using an electrolytic model is that reservoir flow behavior can be approximated by single-phase, steady-state flow according to Darcy's Law. In addition, the formation must be assumed to be homogeneous with equal horizontal and vertical permeability. The wellbore diameter in this study is assumed to be 11¾ in, and the drainage radius of the well equal to 500 ft. The drain holes are considered to have been completed without damage.

THE ELECTROLYTIC MODEL

The producing formation was modeled by forming a sheet of phosphor-bronze into a cylinder 40½ in. in diameter to represent the boundary of the drainage area. This was enclosed in a waterproofed plywood box, and the box filled to an appropriate level with a dilute sodium chloride solution. Solution concentration was adjusted to give a total resistance from

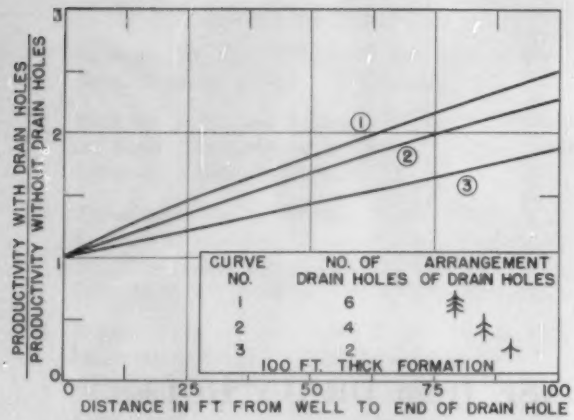

PRODUCTIVITY WITH DRAIN HOLES / PRODUCTIVITY WITHOUT DRAIN HOLES
CURVE NO.
NO. OF DRAIN HOLES
ARRANGEMENT OF DRAIN HOLES
1 6
2 4
3 2
100 FT. THICK FORMATION
DISTANCE IN FT. FROM WELL TO END OF DRAIN HOLE

FIG. 1 — PRODUCTIVITY INCREASE IN AN UNDAMAGED FORMATION.

the boundary to the well of several thousand ohms. A copper wire coated with platinum black located at the center of the cylinder served as the wellbore. Model drain holes were made by soldering together wires of the proper diameter, then bending and trimming them to size. In all cases the drift of the final straight line portion of the drain hole was 90 degrees.

Damaged zones were simulated by lucite cylinders drilled to permit penetration by drain holes. Because lucite is a nonconductor, the model simulated a formation with no permeability within the damaged zone. It was assumed in obtaining productivity ratios from these results that flow through the damaged zone could be neglected in comparison with that through drain holes. Radial flow equations were used to calculate productivity for damaged formations in the absence of drain holes.

Two types of drainhole arrangements were considered. In one, drain holes were assumed to be drilled in pairs at the same depth, the members of a pair oriented 180 degrees apart. Up to four such pairs, or eight drain holes, were considered for each 100 ft of formation. In the other arrangement, four drain holes were drilled at a single depth and at right angles to each other. Where pairs at two depths were considered, the vertical separation of the drain holes was assumed to be 35 ft in the 100-ft formation. With pairs at three depths, the separation between pairs was 25 ft. Sketches of drainhole arrangement are included in the figures and tables to follow to avoid ambiguity. Drainhole length as used in this paper is the horizontal distance from the center of the wellbore to the end of a drain hole. The actual length of the curved hole that is drilled will be somewhat longer.

The resistance between the boundary cylinder and center wire was measured for each model drainhole arrangement using an a-c bridge circuit in which the capacitance of the tank was balanced out. From these data, the flow of current in the solution, corresponding to the flow of fluid through a porous medium, could be obtained for any arrangement under a fixed potential. The ratio of this current to that for the single wire dipping into the solution at the same potential gave the desired productivity ratio.

PRODUCTIVITY INCREASE RESULTING FROM DRAIN HOLES

The productivity increases that may be obtained by drilling drain holes from a well are presented in Figs. 1 through 7 and Tables 1 and 2. The sections of the paper to follow describe these results. The first section presents productivity increases as functions of the length of the drain holes for from two to six drain holes. The second considers the effect of damage around the wellbore. The third section discusses the effect of number and arrangement of the drain holes. Results are included in each section for both 100- and 25-ft thick formations.

EFFECT OF DRAINHOLE LENGTH ON PRODUCTIVITY

The productivity ratio in an undamaged formation is described in Fig. 1 as a function of the length of drain holes drilled in 100 ft of formation. Curves are presented for two, four, and six drain holes arranged in pairs, each pair at a different level. An almost straight line relationship exists between the productivity ratio and drainhole length for drain holes between 25 and 100 ft in length. Thus, any increase in length of the drain holes is reflected in increased productivity. The improvement obtained, however, is moderate. Six 100-ft drain holes only increase the productivity ratio to about two and one-half. Another point for consideration is that in the undamaged formation, more than half of the increase could have been obtained with just two drain holes. Doubling the number of drain holes does not double the productivity.

Similar results for damaged formations are presented in Figs. 2 and 3. In Fig. 2, the permeability is assumed to be reduced to a distance of 6.25 ft from the well, while in Fig. 3, the radius of the damaged zone is taken to be 12.5 ft. Where the formation has been damaged, a linear relationship no longer exists between productivity ratio and length of the drain holes. Productivity increases more rapidly with drainhole length than in undamaged formations, particularly if four or six drain holes penetrate the formation. Comparison of Figs. 2 and 3 with Fig. 1 will show, however, that drainhole lengths in excess of 50 ft are required before the productivity of a damaged well with drain holes approximates that for an equivalent but undamaged formation with the same number, length, and arrangement of drain holes.

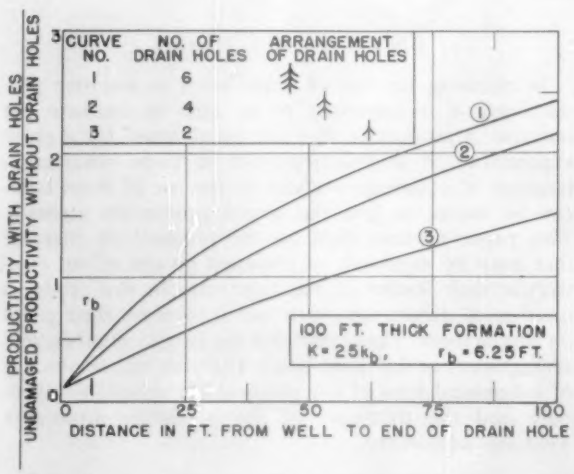

PRODUCTIVITY WITH DRAIN HOLES / UNDAMAGED PRODUCTIVITY WITHOUT DRAIN HOLES
CURVE NO.
NO. OF DRAIN HOLES
ARRANGEMENT OF DRAIN HOLES
1 6
2 4
3 2
100 FT. THICK FORMATION
K = 25k_b, r_b = 6.25 FT.
DISTANCE IN FT. FROM WELL TO END OF DRAIN HOLE

FIG. 2 — PRODUCTIVITY INCREASE IN A DAMAGED FORMATION.

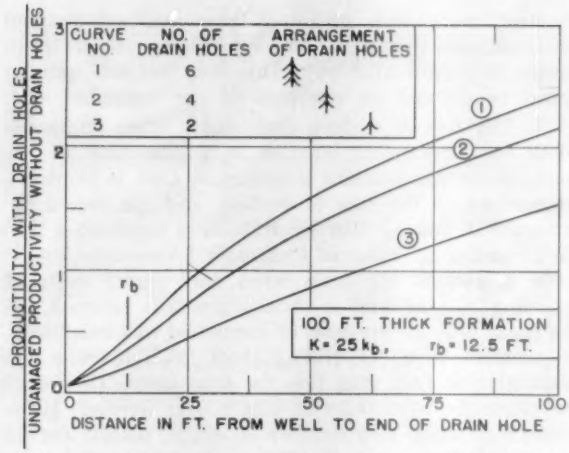

CURVE NO.
NO. OF DRAIN HOLES
ARRANGEMENT OF DRAIN HOLES
1 6
2 4
3 2
100 FT. THICK FORMATION
K = 25 kb, rb = 12.5 FT.
rb
PRODUCTIVITY WITH DRAIN HOLES
UNDAMAGED PRODUCTIVITY WITHOUT DRAIN HOLES
DISTANCE IN FT. FROM WELL TO END OF DRAIN HOLE

FIG. 3 — PRODUCTIVITY INCREASE IN A DAMAGED FORMATION.

Fig. 4 presents results with two drain holes drilled into a 25-ft thick formation. The productivity ratio is plotted against the length of the drain hole. Both damaged and undamaged formations are considered. The productivity ratio in the undamaged formation is again almost a linear function of length once the length exceeds 25 ft. Also, approximately 50 ft of drain hole are required for productivity in a damaged formation to approximate that with no damage and the same number of drain holes.

EFFECT OF DAMAGE IN THE WELLBORE REGION

Productivity ratios for drain holes in a 100-ft sand are plotted as functions of the radial extent of damage in Figs. 5 and 6. The permeability within the damaged zone is 1/25 that elsewhere. Fig. 5 shows results for drain holes 40 ft in length, with curves for two, four, and six drain holes. Fig. 6 presents data for four drain holes, with separate curves for those 20, 40, and 100 ft in length.

These results show that both length and number of drain holes are important factors influencing increased productivity from a damaged formation. Neither the productivity ratio for six 40-ft drain holes nor that for four 100-ft drain holes decreases very much within the range of damage considered. The curves for two 40-ft drain holes or four 20-ft drain holes show a rapid decrease with increasing extent of damage.

In Fig. 7, the productivity ratio is shown as a function of the radius of the blocked zone with a formation thickness of 25 ft. Results for two drain holes, of lengths 20, 40, and 100 ft, are included. Permeability within the damaged zone is 1/25 of that elsewhere. In a 25-ft sand, the productivity ratio decreases almost linearly with increasing extent of damage, within the range of damage considered. The decrease, however, is more rapid for the shorter drain holes.

EFFECT OF NUMBER AND ARRANGEMENT OF DRAIN HOLES ON PRODUCTIVITY

Table 1 includes data for from one to six drain holes arranged in several ways within a 100-ft formation. The length of each drain hole is 40 ft. Both damaged and undamaged formations are considered.

The measured productivity ratios increase gradually as the number of drain holes increases. The increase is somewhat more rapid in the damaged formations. The effects of damage, however, are still evident with even the largest number of drain holes.

Arrangement is of relatively little importance with 40-ft drain holes. Results for four drain holes at the same level and at right angles to each other are very close to those for four drain holes at two levels, by pairs, the members of each pair 180 degrees apart. This independence of productivity increase on arrangement continues for drain holes between about 40 and 60 ft in length. With 30-ft drain holes, the arrangement by pairs is more effective. For lengths greater than 80 ft, the arrangement with four drain holes at right angles to each other should be more effective. The arrangement by pairs, however, with the members of each pair 180 degrees apart, has an additional advantage. If a water flood is to be used as a secondary recovery measure, drain holes at 180 degrees, properly oriented, may permit a close approach to a line drive type of flood. The increased coverage obtained can make the flood much more effective.

Results for from one to four 40-ft drain holes in a 25-ft formation are included in Table 2. Both damaged and undamaged formations are considered. Two drain holes in 25 ft of sand are approximately equivalent to eight in a 100-ft formation. The increase in productivity ratio obtained by drilling the third and fourth of a total of four drain holes is quite small in an undamaged formation. These additional drain holes are a little more effective where there is damage.

CONCLUSIONS

Drain holes drilled out into the formation from a well can give significant increases in productivity. The effects of some of the factors influencing such increases have been described in this paper. The important conclusions to be drawn from the results are as follows:

1. Large increases, such as changing productivity by a factor of 10, can be obtained only when there is initially a zone of reduced permeability around the wellbore. The largest increase obtained for conditions considered in this study was to about 2½ times the undamaged productivity.

2. The distance to which drain holes penetrate is of primary importance. In contrast to some means of improving productivity, drain holes must extend an appreciable distance beyond a damaged zone in order to overcome the effects of damage.

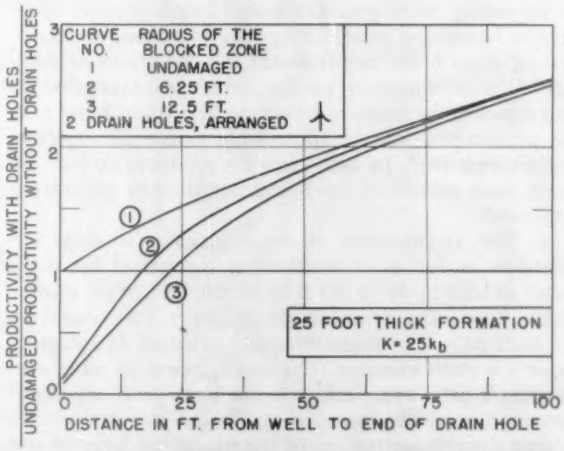

CURVE NO.
RADIUS OF THE BLOCKED ZONE
1 UNDAMAGED
2 6.25 FT.
3 12.5 FT.
2 DRAIN HOLES, ARRANGED
25 FOOT THICK FORMATION
K = 25 kb
PRODUCTIVITY WITH DRAIN HOLES
UNDAMAGED PRODUCTIVITY WITHOUT DRAIN HOLES
DISTANCE IN FT. FROM WELL TO END OF DRAIN HOLE

FIG. 4 — PRODUCTIVITY INCREASE, DAMAGED AND UNDAMAGED FORMATIONS.

TABLE 1 — PRODUCTIVITY INCREASE FROM DRAIN HOLES AS A FUNCTION OF THEIR NUMBER AND ARRANGEMENT (100-FT THICK FORMATION)

Q/Q_o represents the ratio of productivity with drain holes to undamaged productivity without drain holes. The radius of the damaged zone is denoted by r_b. Permeability within the damaged zone is 1/25 that elsewhere. The length of each drain hole is 40 ft.

Number of Drain Holes	r_b, ft	Q/Q_o	Arrangement of Drain Holes
1	0.0	1.18	
2	0.0	1.33	
4	0.0	1.51	
4	0.0	1.55	
6	0.0	1.69	
1	6.25	0.50	
2	6.25	0.82	
4	6.25	1.22	
4	6.25	1.27	
6	6.25	1.54	
1	12.5	0.43	
2	12.5	0.73	
4	12.5	1.13	
4	12.5	1.15	
6	12.5	1.40	

TABLE 2 — PRODUCTIVITY INCREASE FROM DRAIN HOLES AS A FUNCTION OF THEIR NUMBER AND ARRANGEMENT (25-FT THICK FORMATION)

Q/Q_o represents the ratio of productivity with drain holes to undamaged productivity without drain holes. The radius of the damaged zone is denoted by r_b. Permeability within the damaged zone is 1/25 that elsewhere. The length of each drain hole is 40 ft.

Number of Drain Holes	r_b, ft	Q/Q_o	Arrangement of Drain Holes
1	0.0	1.41	
2	0.0	1.77	
4	0.0	2.04	
1	6.25	1.12	
2	6.25	1.65	
4	6.25	2.02	
1	12.5	1.02	
2	12.5	1.53	
4	12.5	1.98	

3. The number of drain holes, while of importance, is secondary to length. Additional length is more effective in improving productivity than increasing the number of drain holes, regardless of the conditions of damage. Where individual sand members are separated by impermeable barriers, however, several drain holes may be necessary to obtain appreciable formation exposure within each sand. In such cases the productivity increase from each section of the formation must be considered separately.

4. The arrangement of drain holes is of little importance as far as productivity is concerned for drain holes extending 40 to 60 ft from the well. With shorter drain holes, the arrangement by pairs (the members of each pair at a single level and oriented 180 degrees apart) is most effective. The arrangement by pairs also permits a close approach to a line drive with additional coverage in a subsequent water flood. Four drain holes placed toward the bottom of the producing interval and at right angles to each other, however, may permit better utilization of gravity drainage where this production mechanism operates. Other less symmetrical arrangements may result in most efficient use of drain holes in a particular well. Thus the best arrangement must be decided on the basis of the individual well.

5. The cost of drilling drain holes, when compared with the anticipated increase in productivity of the well, is of considerable importance. Cost is primarily dependent on the rate of drilling, and has varied between $25 and $250/ft of drain hole based on a limited number of different California formations. Favorable conditions for drain holes may permit costs of about $25/ft or less. A satisfactory cost estimate can be made only on the basis of individual well conditions. Equipment used for drilling short drain holes is less expensive to rent than that for long holes. This tends to offset the advantages of length over number. However, each drain hole includes an initial, sharply curved section that is relatively unproductive for the number of feet actually drilled. The result is that a smaller number of long drain holes requires appreciably less drilling footage to give the same productivity increase.

6. The data included in this paper show that up to a point, the increase in productivity is nearly proportional to the combined length of all drain holes drilled into the formation. Beyond this point, the additional productivity increase per foot of added drain hole length diminishes. Thus for the conditions assumed in this study, 2 to 4 ft of combined drainhole length per foot of formation thickness appears most readily justified. More than 4 ft of combined drainhole length per foot of net sand appears justified only where the additional cost is low, or where damage has reduced productivity permitting additional improvement to be obtained.

A total of 2 ft of drainhole length for each foot of net sand thickness may result in a productivity about 1.7 times as large as that for the undamaged formation. Thus, the additional production provided by drain holes is 0.7 times that for the undamaged formation, or a 70 B/D increase might be expected from an undamaged 100 B/D well. Four feet of drainhole length per foot of formation should give a productivity about 2.1 times that of the undamaged formation. Thus, doubling the drainhole length would contribute only another 40 B/D to production.

In damaged formations, the increases obtained will be larger, with considerable dependence on the degree of damage. Two ft of drainhole length per foot of formation not only can restore the undamaged productivity, but may provide in addition about one-half the production that would be obtained from the undamaged well. Thus, a well with an undamaged potential of 100 B/D, but with production reduced by damage to 20 B/D, might produce 150 B/D after drilling the necessary footage of drain holes. Four ft of drainhole length for each foot of net sand is sufficient to give about twice the productivity of the undamaged formation. Thus, the 20 B/D damaged well with a 100 B/D undamaged potential might produce about 200 B/D with the greater drainhole length. Only 50 B/D of the 200 B/D production, however, would be provided by the extra drainhole length.

The numerical increases presented above are averages from the tabulated results, and thus cannot be

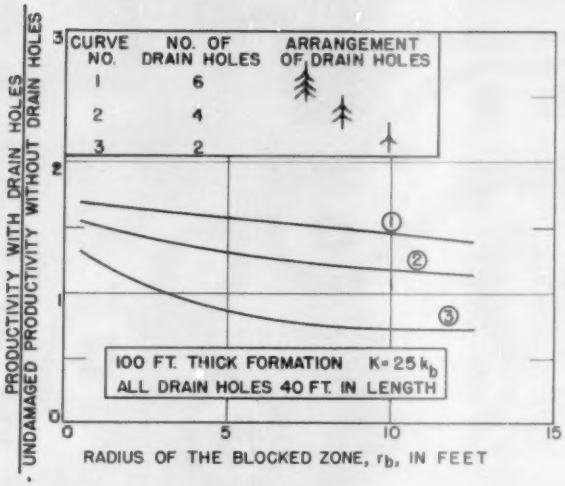

PRODUCTIVITY WITH DRAIN HOLES
UNDAMAGED PRODUCTIVITY WITHOUT DRAIN HOLES
CURVE NO. NO. OF DRAIN HOLES ARRANGEMENT OF DRAIN HOLES
1 6
2 4
3 2
100 FT. THICK FORMATION K= 25 kb
ALL DRAIN HOLES 40 FT. IN LENGTH
RADIUS OF THE BLOCKED ZONE, rb, IN FEET

FIG. 5 — PRODUCTIVITY INCREASE AS A FUNCTION OF DAMAGE.

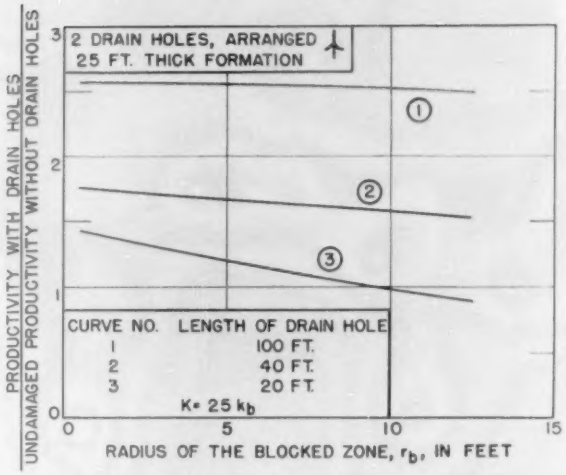

PRODUCTIVITY WITH DRAIN HOLES
UNDAMAGED PRODUCTIVITY WITHOUT DRAIN HOLES
2 DRAIN HOLES, ARRANGED
25 FT. THICK FORMATION
CURVE NO. LENGTH OF DRAIN HOLE
1 100 FT.
2 40 FT.
3 20 FT.
K= 25 kb
RADIUS OF THE BLOCKED ZONE, rb, IN FEET

FIG. 7 — PRODUCTIVITY INCREASE AS A FUNCTION OF DAMAGE.

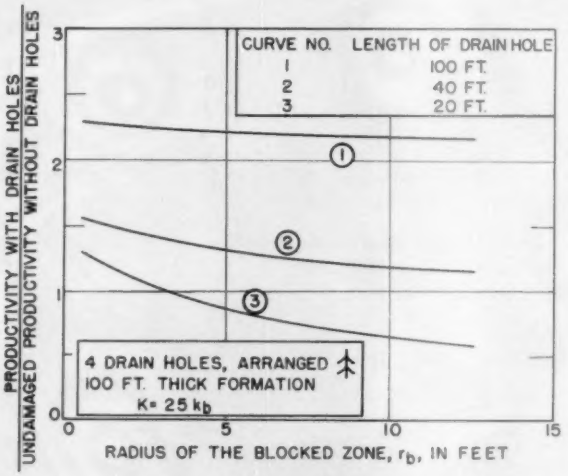
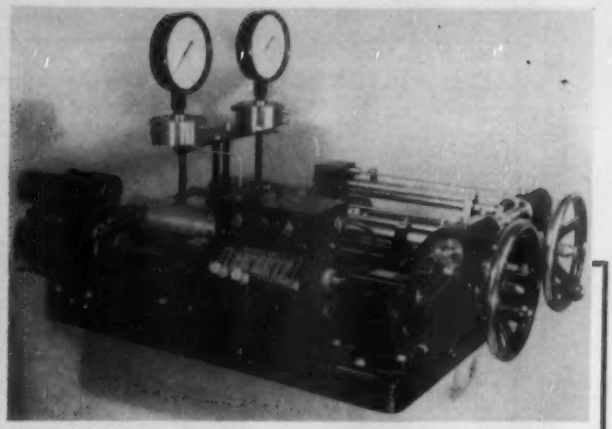

PRODUCTIVITY WITH DRAIN HOLES
UNDAMAGED PRODUCTIVITY WITHOUT DRAIN HOLES
CURVE NO. LENGTH OF DRAIN HOLE
1 100 FT.
2 40 FT.
3 20 FT.
4 DRAIN HOLES, ARRANGED
100 FT. THICK FORMATION
K= 25 kb
RADIUS OF THE BLOCKED ZONE, rb, IN FEET

FIG. 6 — PRODUCTIVITY INCREASE AS A FUNCTION OF DAMAGE.

construed as more than rough estimates for a particular situation. The parameter, combined drainhole length per foot of formation, reduces but does not eliminate dependence of the results on actual formation thickness. The trend is toward less productivity increase with less actual formation thickness for a specified combined drainhole length per foot of formation. Drain holes are most effective in relatively thick formations with vertical, as well as horizontal, permeability. Results included in this paper do not apply, of course, when vertical permeability does not exist.

The productivity increase that may be expected from drain holes and the cost of drain holes have been considered, but not the effect of drain holes on decline rate, well spacing, or other parameters. Yet the results of this limited study are complex. A decision as to the practicality of drain holes, or a decision as to how they should be used, can only be made on the basis of the particular well under consideration. ★★★



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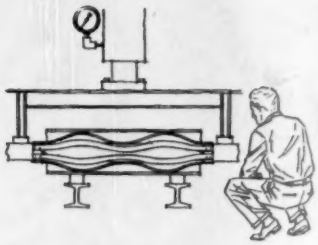

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